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THE ENGINEERING BEHAVIOR OF STRUCTURAL METALS UNDER SLOW AND RAPID LOADING

by

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Approved by

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Final Technical Report

to

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Department of Civil Engineering
University of Illinois
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ABSTRACT

The purpose of this report is to describe an ~~experimental~~ investigation ~~concerned with~~ the behavior of a few structural metals under a range of stress conditions applied in times that correspond to the responses which might be excited in ship structures by underwater explosion or air blast loading, or in building structures by earthquake shock or the explosion of a large scale weapon. The engineering aspects of material behavior are emphasized.

The tests included uniaxial stress applied in either tension or compression, and flexural stress produced by third-point loading of small beams of rectangular section. The rise times of the loadings were varied from a few milliseconds to several minutes. An attempt is made to correlate the results obtained in the uniaxial stress tests with those obtained in flexure.

The applicability of the results of this investigation to the general problem of determining the behavior of structures under transient dynamic loadings producing extensive inelastic deformations is discussed ~~briefly~~.

ACKNOWLEDGMENT

The investigation described in this report was performed by staff members of the University of Illinois in cooperation with the Office of Naval Research under Contract Nonr-1834(01), Project NR-064-[illegible]. The work was conducted in the Structural Research Laboratory of the Department of Civil Engineering under the general direction of Professor N. M. Newmark, Head of the Department. The project was under the supervision of Dr. J. M. Massard, Research Assistant Professor of Civil Engineering. The latter part of the work was the direct responsibility of R. A. Collins, Research Assistant in Civil Engineering. The instrumentation used throughout the investigation was, in general, the responsibility of V. J. McDonald, Research Associate Professor of Civil Engineering.

The initial development of the basic testing apparatus and the preliminary testing was done by Dr. Massard prior to the beginning of Contract Nonr-1834(01). For completeness, some of the results of other preliminary studies which predate the contract are included in this report. These were investigations described in Master's Theses submitted to the Graduate College of the University of Illinois by L. B. Smith and J. W. Storm. This early work was supported in part by funds obtained from the Bureau of Ships, Department of the Navy under Contract NObs 62250.

THE ENGINEERING BEHAVIOR OF STRUCTURAL METALS UNDER SLOW AND RAPID LOADING

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1. GENERAL INTRODUCTION

1.1 Introduction

The purpose of the investigation which was conducted at the University of Illinois under Contract Nonr-1834(01) was to determine the time sensitive stress-deformation characteristics of the more commonly used structural metals, and the engineering significance of this information in the solution of problems concerned with the behavior of metal structures under transient dynamic loads producing extensive inelastic deformations.

The work which was done on the project can be divided arbitrarily into three related parts: (1) The testing of structural metals under uniaxial stress conditions which are produced slowly or rapidly, (2) the correlation of these behaviors with the ones obtained under conditions of slowly or rapidly applied flexural stress, (3) the development of the special testing apparatus required for the experimental work. These phases also form the major divisions of this report.

In the first part of the report is discussed the basic apparatus developed at the University of Illinois for use in the application of slow to rapid loads to uniaxially stressed coupons, small beams, or model frames. Since special fixtures and instrumentation were necessary for each type of test, only the basic apparatus will be discussed in this section. The details of the fixtures and instrumentation will be described in the other sections of the report which pertain to the actual testing programs; these are Sections 2 and 3 which describe respectively the uniaxial stress studies and the flexural stress studies.

The investigations conducted at the University of Illinois as a part of Contract Nonr-1834(01) were concerned with the engineering aspects of the behavior of the materials and structural elements under conditions of slow and rapid stressing. The metallurgical and fundamental physical nature of the deformation process was beyond the scope of this project. However, an attempt was made to classify the materials which were tested by evaluating and recording the metallurgical natures and the chemical compositions involved.

1.2 Scope

In the investigation described in this report small specimens of several sizes, shapes, and materials were tested at room temperature under stress conditions which for some steels included uniaxial tension, uniaxial compression, and flexure. These "stressings" were applied with a specially constructed machine that permitted independent control of the "rise" time of the loading, the maximum load, duration of the load, and the time of load decay. (This machine was designed not only for this investigation, but for general use as a pulse loading unit capable of applying a controlled load of 20,000 lb maximum to small structural elements in times as short as 0.005 seconds.)

In most of the tests, the loads were held at constant levels after application until the yielding process had been completed. The main variables of the experimental investigations were:

Uniaxial Tension

1. Rise time of load (0.005 second minimum to approximately 100 seconds)
2. Maximum stress level
3. The type of steel (semi-killed, rimmed, low-alloy)

Uniaxial Compression-Tension

4. Manner of loading (tension, compression, and reverse loadings)

Some secondary variables of the uniaxial tests were:

a. Manner of treatment (as-rolled, annealed before machining, annealed after machining)

b. Surface finish (as-machined, polished, notched)

Flexure

5. Level of maximum load

Using oscillographs and associated instrumentation having adequate response characteristics, records with respect to time were taken of the nominal specimen resisting stress, surface strains, and average elongation over the "gage" length of the specimen. From these records the relations between stress, strain, and time were determined for the various tests.

The results of the uniaxial tension and compression tests are presented and discussed in terms of (1) the time delay to the initiation of a significant amount of yielding, (2) the rate of general yielding where applicable, and (3) the general nature of the stress-strain-time behavior of the various metals tested.

In the slow and rapid flexural tests of small beams of rectangular section under third-point loading, enough information was obtained that the time dependent stress-strain behavior in the pure flexural region of the beam could be determined. An attempt is made to correlate this behavior with the information obtained from uniaxial tests of the same material.

2. RAPID LOADING AND STRAINING EQUIPMENT

2.1 Introduction

The equipment used for producing the loads and the deformations required during the course of the project consisted of two types; those in which nominal deformation was the quantity most nearly independent of the specimen behavior (standard hydraulic and screw-type universal testing machines and a specially constructed hydraulic actuator), and the slow and rapid pneumatic loading unit with which nominal loads that are nearly independent of specimen response could be produced. The pneumatic unit is hereafter called the pulse loading unit.

The Baldwin universal hydraulic testing machine which was used as the load standard in all dynamometer calibrations, was also used for many of the slow tests run at rates conforming to ASTM specification A 370-56T. However, in the later stages of the project, for convenience in use of the oscillographic equipment with which all slow and rapid tests were recorded, a hydraulic actuator system affording nominal straining control at slow rates of deformation was devised. This could be quickly connected in series with the pulse loading unit so that no change of either instrumentation connections or specimen fixtures was necessary in changing from slow straining tests to rapid loading tests.

2.2 Description of the Loading Apparatus

For the initial purposes of the investigation, a device that would produce a rapid loading pulse, that is, a pulse that is nearly independent of specimen response, was very desirable not only because such a device would permit producing the desired loading without the need of accurate knowledge of the specimen's response characteristics, but also because nearly identical loading pulses

could be applied easily to structural components, couples, or frames having varying response characteristics. Other requirements were that the minimum rise and decay times of the loading pulse should not exceed approximately ten milliseconds, that both the magnitude and duration of the loading should be independently controllable, and that the maximum loading stroke should be at least four inches with an associated drop in load of not more than 30 per cent.

The 20-kip pulse loading device shown in Figs. 1, 2, and 3 was developed to satisfy these requirements. This unit is a piston device in which the load output is the result of differential pressure. Compressed nitrogen or helium is used as the pressure source. The rapid application and release of the load can be achieved through the use of solenoid triggered slide valves to obtain the timed pressure release from the two chambers of the device.

2.3 Control of Loading

The use of this device permits the application of a loading pulse that may begin from a static level ranging from 20 kips tension to 20 kips compression, undergo a rapid change of plus or minus 20 kips maximum (with the restriction that the prepulse load plus the dynamic change in load can not exceed the limits of plus or minus 20 kips), and then return rapidly to zero load. The duration of the peak load may be varied from a few milliseconds to many hours. The rise and decay times of the loading pulses are controllable by adjusting the size of the pressure release orifices. The minimum time for either rise or decay of the load is approximately six milliseconds. Using the adjustable orifices, it is possible to increase the time for rise or decay of the load to approximately half a second, and, of course, loadings at relatively slow rates can be achieved by the slow build-up of pressures in the chambers of the unit using the manual pressure supply system. A few possible loading pulses are shown in Fig. 4.

2.4 Past Usage in Testing

In the investigation described in this report the 20-kip pulse loading unit was used for the rapid uniaxial tension and compression tests, and also for the experiments involving rectangular beams under third-point loading. In addition to these investigations for which the testing arrangements are shown in Figs. 7 and 31, the loading unit was used also in a series of tests of small model frames under both slow and rapid loadings The arrangement for these experiments is shown in Fig. 5.

Since the successful development of the 20 kip loading unit, machines of larger capacity based upon its design have been constructed at the University of Illinois. One of these machines is shown in Fig. 6. This machine has a capacity of plus or minus 60 kips and a minimum loading time of approximately 15 milliseconds under ordinary usage.

2.5 Description of the Slow Straining Unit

As was mentioned in the introduction to this section, a hydraulic actuator which can be connected in series with the 20-kip pulse loading unit was provided so that straining tests at slow rates could be performed conveniently without changing the instrumentation or the manner of specimen connection. A schematic diagram of this unit and the associated pressure control system is shown in Fig. 8. The entire testing arrangement is shown in Fig. 7.

2.6 Summary

A general purpose loading unit has been developed which permits control of the load pulse as follows:

(a) The magnitude of the tensile or compressive load pulse can be varied from approximately 2000 to 20,000 pounds, corresponding to

main chamber pressures of 100 to 1000 psi. (100 psi is the lower limit of consistent operation.)

(b) The time interval between the initiation of the load and the start of load release can be varied from a 0.007 second minimum to long hand-timed intervals.

(c) The rise time of the load can be varied from a 0.005 second minimum to 1.5 seconds using the slide valves and variable orifices, or from a 5 second minimum to long times using the pressure regulators and/or needle valves to control pressure.

(d) The decay time of the load is independently variable. The range possible is the same as that of the rise time since the two slide valve assemblies are identical.

For use in conjunction with this apparatus, an attachment for the control of slow straining rates has been provided. Therefore, in one location, apparatus is available with which slow tests may be run under either loading or straining control, and also with which rapid loading pulses can be applied.

3. UNIAXIAL STRESS TESTS

3.1 Introduction

During the past few decades much effort has been devoted to determining the behavior and the nature of the materials with which man builds. The more commonly used the material, the more extensive have been the investigations. Consequently, a great deal of information is available concerning the most commonly used structural metal, steel. However, the fact that steel is an alloy of iron and therefore can have greatly different properties has made the determination of its behavior in all its various forms a never ending task[10, 15, 26, 40*]. As fast as new instrumentation capable of more accurate measurement or better time resolution has been developed investigators have attempted to extend their knowledge of materials. The development of the wire resistance strain gage and the common availability of oscillographic equipment useable in the microsecond range has led to the comparatively recent work of Davies, and Clark and Wood, et al., and has therefore resulted in the acquisition of new knowledge pertaining to the time sensitive behavior of metals.

While it is probable that no other materials have been the subject of as many investigations as structural steel and aluminum, little information is available about the stress-deformation characteristics of these metals in the range of strain rates corresponding to those that might be created in the members of typical structures by large dynamic forces, that is, strain rates increasing from "static" to about 1 in./in. per second. Furthermore, as regards iron alloys, the deformation characteristics are greatly affected by extremely small concentrations of the alloying elements and also by the form of their presence (as solutes or precipitates).

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* Numbers refer to entries in the bibliography. The bibliography includes references for background information in addition to those references noted in the text.

In addition to these difficulties, no satisfactory theory based on chemical composition has been developed with which quantitative predictions of the time sensitive behavior of these metals can be made, although qualitatively many characteristics can be explained[6, 16, 17, 29, 41]. Therefore, the time dependent stress-deformation characteristics of specific metals usually must be determined by experimental means.

The uniaxial stress tests described in this report were performed to obtain specific stress-strain-time information for a few of the more commonly used structural materials.

3.2 Description of Uniaxial Testing Series

3.2.1 Types of Specimens

The materials which were investigated included the following: rimmed steel from one inch bar stock in the as-rolled and annealed condition, semi-killed steel from one inch plate stock in the as-rolled condition, fully-killed steel, ASTM A-7 steel obtained from a 4M section, two low-alloy steels, a chrome-nickel steel, a steel meeting ASTM specification A-242, and USS T1 steel. In addition 60 61-T6 aluminum was tested. A summary of the materials tested is given in Table 1 and a description of the system used for specimen designation is presented in Table 2.

In the preliminary series, composed of specimens having an area of 0.100 sq in., the rimmed steel bar stock (RB) and the semi-killed steel plate stock (SP) were tested as-rolled (A), annealed after machining (B), and annealed before machining (C). In addition, some of the specimens of the preliminary series were tested polished smooth (S) and some with a small circumferential notch (N).

Following these tests it was decided to test these two steels as-rolled since metallurgical investigations revealed that the microstructures were quite uniform. These were the series called 2 MRBA, 2 SRBA, 2 SSPAL, and 2SSPAT..

The bar stock specimens were, of course, aligned axially with respect to the direction of rolling of the bar. The plate stock specimens were oriented with their longitudinal axes either parallel to the direction of mill rolling (L) or with their axes transverse to the direction of mill rolling (T).

The tests of the NS, NL, and NN series were not instrumented as completely as the others, in that only resisting stress-time and SR-4 gage strain-time information was recorded.

The dimensions of the various specimen types are given in Figs. 9, 11, 12, and 13. The form of the specimens varied from areas of 0.100 sq in. to 0.200 sq in. and in form from the gently curving profile illustrated in Fig. 9 to the profile shown in Fig. 13b which was developed for use in either tension or compression. Table 2 also provides a key to the profile used for the various series of tests.

3.2.2 Manufacture of Specimens

The specimens which were tested in the as-rolled condition were machined from band sawed blanks using a maximum depth of cut on each pass of no more than 0.02 in., which, under the oil coolant used, raised the specimen temperature to no more than 150 degrees F. The final cut to about 0.002 in. oversize for the specimen to be polished, was about 0.005 in. in depth. Following this cut, the specimens were polished by hand held emery cloth to the final dimensions and to a finish that varied from about 11 microinches r.m.s. to some 20 microinches r.m.s., with an average finish of about 15 microinches r.m.s. as indicated by a type PAC, serial 11 (Profilometer) manufactured by the Physicists Research Company, of Ann Arbor, Michigan.

The as-machined specimens were cut to the final dimension using a final pass of about 0.005 in. The surface roughness of these specimens varied from about 100 to 200 microinches r.m.s. with an average of about 150 microinches r.m.s.

As was mentioned in Section 3.2.1, a few of the preliminary series specimens were notched circumferentially (1N). These were "V" notches about 0.01 in. wide and 0.01 in. deep.

Following the pretest measurements of surface roughness and diameter, the SR-4 gages, if used, were applied to the gage section of the specimens. During this process the specimens were heated to about 180 degrees F for a period of some four hours. This may have aged the material somewhat with respect to the residual stresses resulting from the machining.

The procedure listed above, which is that followed in the preparation of the as-rolled specimens, was followed in preparing the "annealed before machining" specimens beginning, of course, with the annealed specimen blanks.

In the case of the "annealed after machining" specimens, the heat treatment, performed in an electric furnace by heating a tube containing the machined specimens sealed in an atmosphere of helium, was followed by the removal, by polishing, of the final 0.002 in. left by the machining process.

The ML, MN, and NHY specimens were prepared elsewhere and sent to the University for testing.

3.2.3 Metallurgical Properties and Chemical Compositions

In commenting upon the results of the metallurgical investigation performed by the Metallurgical Department of the University of Illinois on most of the steels used for the specimens described in this report, the authors refer the reader to the summary given in Table 3, and the metallographs of Fig. 14.

These studies did show that the steels were very uniform in their so-called as-rolled condition and that consequently for this reason the annealing and spherodizing were not necessary to obtain consistent results.

The almost complete decarburization of steel NS, and the broadly decarburized bands of steel NR should be noted. It is possible that this decarburization greatly affected the yield behavior of the materials as compared with that of the other steels.

The chemical compositions of the steels as determined in a check analysis by the R. W. Hunt Company of Chicago, are given in Table 4. Inadvertently the oxygen content of the steels was not requested; this is regrettable since this would probably be one of the more important differences between the rimmed and the semi-killed steels.

3.3 Description of Testing Procedures

3.3.1 Instrumentation

To record the data from the preliminary series of tests, the four channel cathode ray oscillograph shown in Fig. 15 was used. This equipment was virtually flat in response from some five cps to thirty kcs. The lower limit was imposed by the instability of the D.C. preamplifiers which caused significant drift in the traces over times as short as 0.1 or 0.2 seconds. For this reason, the equipment was not satisfactory for the recording of tests involving durations of several seconds.

On the basis of the records obtained with the CRO equipment, it was seen that the Hathaway magnetic oscillographic equipment available in the laboratory would have response characteristics adequate for the faithful recording of the resisting stresses and strains developed in the rapid load tests with the advantage of excellent long time stability that would permit use of the instrumentation for the recording of slow tests as well. Therefore, the magnetic oscillographic equipment, shown in Fig. 16, was used for the main series of tests. This equipment includes a Hathaway Type S-14C magnetic oscillograph, in which were used Type OC2,

Group 2-3 recording galvanometers. The Type MRC-18 Hathaway carrier strain amplifier system was modified using an external carrier oscillator and power supply which had characteristics superior to those of the original equipment. The usable upper frequency limit is about 450 cps, while the lower limit, as mentioned above, is D.C. A block diagram of the Hathaway equipment is shown in Fig. 34.

The phenomena recorded versus time for the preliminary testing series were the following: (1) the output of an SR-4 gage dynamometer recording the stress developed on the end of the specimen opposite that to which the load was applied; and (2) the output of two SR-4 strain gages attached diametrically opposite each other on a gage section of a specimen. On the 2RB, 2SP, NR, NHY, NL, and NN series the output from an extensometer connected across the gage length was recorded also. The dynamometer-specimen-extensometer arrangement used for most of these tests is shown in Fig. 10. In all other testing series, measurements included the output of the dynamometer as before, but strains were obtained from a dual range spring type extensometer connected across the specimen. This extensometer had two independent SR-4 bridges, the outputs of which were recorded with different sensitivities so that the entire range of strains could be resolved adequately.

The various dynamometer-instrumentation systems were calibrated "statically" versus the load measuring system in a 120,000-lb Baldwin universal hydraulic testing machine. In checking the accuracy of the dynamometer-oscillograph load measuring system, measurements from slow straining test oscillograms were compared with the load dial readings taken on the Baldwin machine at corresponding times. Usually the loads were within about 100 lb out of 10,000 lb with an occasional maximum error never greater than 300 lb. That is, the usual error was about ± 1 per cent (and usually lower) with a maximum error never observed to be greater than ± 3 per cent.

In the tests in which SR-4 gages were attached to the gage section of the specimen, bending could be determined. The percentages of bending ranged as high as 15 per cent in some few cases but generally were less than 5 per cent. The alignment procedure possible with the development of the uniaxial tension-compression fixtures was such that the percentages of bending were usually less than 5 per cent.

The extensometers that were used at various times throughout these investigations were all of the flat spring type shown in Figs. 10 and 13. This type of extensometer met requirements for range, sensitivity, dynamic characteristics, and simplicity. In these "transducers", flexural strains in the flat springs were measured with SR-4 gages connected as four arm bridges with all arms active, so that a strain magnification of four was obtained along with temperature compensation. The extensometer last used had two complete bridges of SR-4 gages on them so that two different sensitivities could be used to resolve the total range of specimen extension. Therefore, in these later tests SR-4 gages were not used on the specimens.

Just prior to each test, calibration traces were recorded on the oscillogram by shunting the respective bridges with precision resistors whose equivalence in terms of the quantities being measured had been determined earlier. Usually the complete dynamometer and extensometer-instrumentation channels were calibrated directly before and after every series of tests and, in some cases, in the middle of a long testing series.

It is believed that the total errors associated with measurement of nominal load are no more than ± 3 per cent, and that the total errors measured with the determination of extension between the points of attachment of the extensometers are no more than ± 5 per cent.

A major problem associated with interpretation of the results of the tests in which extension was measured across a reduced gage length is the determination of the effective gage length of the specimens throughout the entire range of deformation. The study which was made of this problem is reported in Section 3.3.6.

3.3.2 Slow Tests

From the summary of the testing, presented in Tables 5, it can be seen that slow tests, with two exceptions, were performed in the Baldwin universal testing machine, or the pulse-loading machine with or without the slow straining attachment. The equivalent elastic strain rates used for these tests were within those allowable under ASTM specification 370-56T. Since a rather complete summary of the conditions under which these tests were run is given in Table 5,* very little discussion is necessary in the text.

It is to be noted that slow tests of the PBA specimens which were tested in the Baldwin machine produced yielding at lower stresses than those which were tested in the pulse loading machine. However, no such difference in yield strength was obtained for specimens of the SPA series. The differences between these series of tests were the following: (1) the static specimens which were tested in the Baldwin machine were "pricked" on the gage area by the extensometer points (which might affect yielding behavior); (2) slightly different loading rates were used in

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* In Table 5, the constants C, C_1 and C_2 are used within a test series to differentiate between the conditions under which each test was run. For the rapid tests, $C = \sigma_{uy} = \sigma_{ly}$.

In Table 5 and in the stress parameters used in this report:

σ_{uy} = upper yield stress
σ_{uy}^* = upper yield stress in a slow straining test
σ_{ly} = lower yield stress
σ_{ly}^* = lower yield stress in a slow straining test
$\sigma_{max} = \sigma_m$ = ultimate strength of a material

the two machines, and (3) the smoothness of application of loading between the two machines may have differed.

In Figs. 17a and 17b are shown photographic reproductions (about half size) of the type of oscillograms which were produced during the slow tests in the Baldwin machine as compared with the pulse loading machine.

3.3.3 Machine Vibration Tests

To determine whether any significant difference existed in the smoothness of the loadings produced by the three testing machines used (the Baldwin machine, the pulse loading machine, and a Riehle screw type testing machine), an attempt was made to measure the vibrations induced in the test specimens by operation of these testing machines. Within the sensitivity of the recording instrumentation no vibrations were evident in the loading produced by either the Baldwin machine or the pulse-loading machine. However, vibrations having an amplitude of some 30 or 40 microinches per inch of strain were apparent in the tests performed in the Riehle screw type machine.

3.3.4 Residual Microstrain Determination

Many metals, but not including mild steel, do not exhibit a perfectly linear relationship between applied stress and resulting strain or vice versa, even for relatively low values. Of course, the degree to which this holds true is somewhat dependent upon the sensitivity of measurement possible with the method used for observing stress and strain. While mild steel does have a nearly linear and almost perfectly elastic stress-strain relationship for relatively low levels, a departure from linearity and from elastic action does become evident at stress levels above something on the order of one-half of the nominal yield strength of the steel.

Some investigators[35, 37] have suggested that a critical amount of inelastic "microstrain" may be necessary before a general yielding condition is initiated. (In this report the term microstrain will be applied to all inelastic straining preceding the development of the general yielding condition.) It follows, then, that a difference in the character of the microstraining which precedes general yielding would be related to the nature of the dynamic yielding behavior. However, as a matter of interest, a few cycled loadings were applied to a few specimens of the SRBA, MRBA, and RSFA series in the Baldwin hydraulic testing machine, the pulse-loading machine, and the Riehle screw type testing machine. The straining cycles, which had a "period" of about 2 minutes (during which about one minute was required for the straining and one minute for making the residual strain measurements), were of successively increasing magnitude culminating in the yielding of the specimen.

Preceding and following each cycle of straining, the SR-4 gages attached to the gage section of the specimen were read using a Baldwin Type L strain indicator. From these readings the residual strain resulting from each strain cycle was determined. The results which are presented in Fig. 18 indicate that in these tests general yielding was preceded by inelastic "microstrain" on the order of 20×10^{-6} in./in.

5.3.5 Rapid Uniaxial Tests

A description of the tests and the results are presented in Table 5. A study of these tables will reveal that in most of the rapid tests loads were applied rapidly to a constant level, and were held at these levels throughout the duration of the test until yielding had nearly stopped, usually some four or five seconds after its commencement. Following this the loads were released rapidly to zero. In most of the test series, identical specimens were tested at either the nominal "static" rates or with rise times of loadings on the order of 0.006

seconds. The tests were run at stress levels ranging between the static upper yield stress and the maximum strength of the specimen material so that a range of delay times and of rates of general yielding could be obtained.*

In the 2RB and 2SP series of tests, three rise times of loadings were used; 0.005 seconds, 0.10 seconds, and 0.50 seconds.

For the NR, PS, Q, K, T, and L series, the loads were applied to a few specimens in tension and to the others in compression. Only in the case of the NR series were the stresses reversed after the specimen had been initially yielded under a stress of the opposite sense.

As has been mentioned earlier, the phenomena recorded versus time for all series included nominal resistance and a measure of strain obtained with either SR-4 gages alone, SR-4 gages in combination with an extensometer, or a dual range extensometer.

Photographic reproductions, about one-half size, of oscillograms illustrating the loadings mentioned above and also typical results are shown in Figs. 17c to 17f.

Before each of these tests, as well as before each slow loading rate test, a small load (corresponding to a stress of no more than 10,000 psi) was applied as an aid in aligning the specimen with respect to the loading axis. If the SR-4 gages on the specimens so instrumented indicated a bending strain greater than about 5 per cent of the axial strain, the specimen was readjusted until the bending was less than that value. On the specimens not having SR-4 gages the small pretest load was applied and released to "settle" the specimen in its seat, a procedure

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* In Table 5, the magnitudes of the rapid loads are listed under either σ_{uy} or σ_{ly}. These expressions for stress are equivalent in rapid tests.

which had produced satisfactory alignment of most specimens instrumented with SR-4 gages.

3.3.6 Effective Gage Length

As was mentioned earlier, a problem associated with use of the information obtained from the uniaxial stress investigation is that of relating extension determined from an extensometer attached across the shoulders of the reduced gage length of a specimen to the actual effective strain in the specimen. For small strains of an elastic specimen the effective gage length can be computed and is a constant times the actual gage length of the extensometer. However, when yielding occurs in the specimen, the effective gage length will change with the magnitude of that yielding. This has been indicated by a series of experiments designed to provide information concerning this matter. In Figs. 19 are shown the results of this investigation. Figs. 19a and 19b indicate that prior to the beginning of yielding, the effective gage length of a shouldered specimen of mild steel was approximately equal to the computed "elastic" value. As the specimen yielded, the effective gage length dropped rapidly to its lowest value which coincided with general yielding. As the specimen strain hardened, the value of the effective gage length increased. For specimens made of a material that exhibited no upper-lower yield point phenomena, the variation in effective gage length was less extreme and no increase of effective gage length with strain hardening was indicated. This is illustrated in Figs. 19c and 19d.

In the RB and SP series specimens the effective gage length after yielding had occurred was assumed to be constant. The value used was obtained by direct calibration during slow straining rate tests of the "static" specimens. For the PS, Q, K, T, and L materials, the effective gage length used was that determined from pilot tests of the same material. All strains as reported in this report are corrected for the effect of yielding upon the effective gage length.

3.4 Results of Uniaxial Tests

3.4.1 General Time Sensitive Behaviors of the Materials Tested

It is comparatively well known that metals having a body centered cubic lattice structure usually yield in a discontinuous manner under slow rates of straining. It has been shown that the same materials when subjected to rapid loading or straining yield in a manner indicating relatively large time sensitivity. Steel in the commonly used form is one of these materials, and therefore its yielding behavior differs considerably from that of a material such as aluminum 6061-T6.

It is a characteristic of mild and low-alloy steels that, under a slow relatively constant rate of nominal uniaxial straining at room temperatures, their resistance goes through four rather arbitrary stages: (1) the elastic range terminating in (2) microstraining followed by the development of the condition of (3) general yielding (in which the level of resistance is a function mainly of the rate of straining) which in turn is followed by the advent of (4) strain hardening and subsequent fracture. The four stages of the nominal resistance-deformation characteristics of these metals are quite evident in the slow straining rate tests, but, of course, are no less present in tests run under other conditions, such as slow constant rate of increase in nominal stress. Of the four stages mentioned, the middle two, microstraining and general yielding, are quite time sensitive; the elastic range is almost insensitive to time; and the range beyond the commencement of strain hardening is only slightly time sensitive.

The time sensitivity associated with what in this report is called the microstraining phenomena has been termed the "delayed yield" effect. This is perhaps best revealed under tests involving rapid stressing to a constant stress level such as were performed in this investigation using the 20-kip pulse loading machine.

In the materials studies presented in this report the time delay in yielding is defined arbitrarily as the interval between the time at which the stress first reached a value corresponding to the lowest upper yield stress obtained in a slow test, and the time at which yielding had become general enough that the apparent modulus (nominal stress/nominal strain) had dropped to about 2/3 E. Delay time so defined has engineering significance in that it is related at one end to a stress level high enough to result in yielding under slow loading or deforming conditions, and at the other end to a parameter involving both stress and strain which has an arbitrary value indicative of an amount or yielding sufficient to mark the beginning of general yielding.

The rate of general yielding effect (usually termed somewhat ambiguously the strain rate effect) is most evident perhaps in tests performed at various constant rates of nominal strain, but it will also be apparent, of course, in tests in which nominal stress rather than nominal strain is the factor most nearly independent of specimen behavior. Such is the case in the "rapid loading to constant stress level" tests. After general yielding has begun (following the delay in yielding if present) the specimen will deform at a rate which is dependent upon the stress level being maintained by the pneumatic loading unit. Since the several tests are run at different constant stress levels, both delayed yield and rate of general yielding information can be obtained from a single test series.

For most mild steels the transition between the general yielding condition (flat yield region in the constant rate of straining test) and the region of strain hardening is somewhat more gradual than that between the other stages. (Of course, the "gradualness" is largely dependent upon the time resolution possible with the recording techniques used.) The tests run at the University of Illinois

on mild and low-alloy steels indicate that for a particular steel the transition begins at about the same total strain regardless of the rates involved.

In a rapid test to a constant stress level the straining finally ceases at a total strain which usually agrees well with that corresponding to the strain obtained at the same nominal stress under slow loading or deforming conditions.

For metals such as high-alloy steel, structural aluminum, etc., yielding under slow rates of straining is not a discontinuous process, and the behavior under rapid loading is not as time sensitive as is the case for mild steel. This is indicated in the results for the HHY, USS T-1, and 6061-T6 materials.

3.4.2 Results of Tension and Compression Tests

In Fig. 20 is presented in three dimensions the relation between stress, strain, and time as obtained from uniaxial tests of mild steel involving slow and rapid loading to constant stress levels. In this relationship the so-called delayed yield and rate of general yielding behavior are quite evident. Stress-strain and strain-time relationships representative of the materials tested are shown in Fig. 21. These contain the same information as is shown for one material in Fig. 20. The information which is presented in these figures is abstracted in the form of delayed yielding and rate of general yielding information where these phenomena were present, and in the form of various times required for yielding to progress to specified values of the nominal secant modulus (nominal stress/nominal strain) where delayed yielding and rate of general yielding behaviors were not pronounced. In Tables 3 are presented these values for all of the tests which were performed.

The delayed yielding and rate of general yielding behavior is presented respectively in Figs. 22, 23, 24, 25, and 26. In the first of the figures of each the values are presented versus the nominal stress, and in the second and

third, versus a stress parameter involving, in the case of delayed yielding the static upper yield stress, and, in the case of rate of general yielding, the lower yield stress obtained under a rate of straining corresponding to approximately 10^{-3} in./in./sec. These basic values were obtained under slow straining of the specimen materials in conformance with ASTM Specification A370-56T, and therefore can serve as a basis for extrapolation of these results to other materials which are similar but which have values of upper and lower yield stress different from those obtained in this investigation.

There was little noticeable difference in the behavior of the materials which were tested under both initial tension and initial compression, that is, ASTM A-242 steel, USS T-1 steel, a fully-killed mild steel, and 6061-T6 aluminum. If the reader wishes to make further comparisons, he may obtain from Table 1 the information concerning the type of test and from both Table 5 and Figs. 22 through 26 the results which were obtained.

5.4.3 Results of Preliminary Reversed Stress Tests

As can be seen from Table 5a, a few tests were performed with a reversal of loading subsequent to initial testing. The material from which these specimens were made was the semi-killed plate stock used for the 2SSFA series, and the BF series flexure tests described in Section 4 of this report. The dimensions of the preliminary stress reversal specimens, the specimen profile, and the manner of attachment to the testing apparatus are shown in Fig. 12. There were several disadvantages in the use of this type of specimen, namely, the attachment of the extensometer to depressions punched into the surface of the specimen, the non-uniform diameter of the specimen, and the relative difficulty of attaining axiality of the load. However, the results are nevertheless interesting, as can be seen from Figs. 28 through 30.

In Fig. 27 the relation between the upper yield stress parameter and the secant modulus (nominal stress/nominal strain) for the slow loading tests is shown. These curves indicate that yielding was rather gradual in these specimens and began at a stress which was considerably lower than that which was arbitrarily used as the upper yield stress of the material. In Fig. 28 is shown the effect of reversal of loading following slow yielding. This is the so-called Bauschinger effect; the fact that after having been yielded in one direction, subsequent reversal without aging will produce almost immediate inelastic behavior at relatively low strain with no evidence of an upper-lower yield behavior.

The results which were obtained in the four rapid stress reversal tests are shown in Fig. 29 in the form of strain-time relationships. In these tests a reversal of loading was applied within a minute or so of release of loading following yielding in the direction in which the loading was initially applied rapidly. Therefore, these were not rapid in the sense that the entire stress-time relationship including reversal was imposed within a very short period of time. However, the change of stress from the initial zero level to the constant stress levels indicated in the figures was rapid. Again a behavior which could be called the Bauschinger effect in rapid loading is evident in that no delay in yielding was apparent upon reversal of loading in a direction opposite to that used in initial yielding.

Because of the non-uniform diameter of the specimen profile used in these preliminary reversed loading tests and the consequent difficulty in relating extensometer deformation to unit strain, no attempt was made to interpret the results of the rapid reversed loading experiments in the form of rate of general yielding information.

In another series of stress reversal tests, an initial slow loading to a level below that which would cause general yielding was followed by a rapid reversal of loading to a level sufficient to cause yielding. As can be seen from Figs. 30, a delay in yielding was obtained in all of these tests, and this delay agreed well with the delay times obtained in the loadings of virgin material in the previously mentioned rapid tests.

3.5 Summary of Results for Uniaxial Stress Tests

3.5.1 Summary of Results

The results of the slow and rapid uniaxial stress tests which were performed on many materials in initial tension and initial compression, and on one material in complete stress reversal, have been presented in the form of tabulated results in Table 5 and in the various figures mentioned previously. In general terms the results can be summarized as follows.

(1) The metals tested which exhibited a pronounced upper-lower yield point behavior under conditions of slow straining, and had stress-strain relationships with discontinuities in slope, also exhibited the time sensitive behaviors termed delayed yielding and rate of general yielding (defined earlier in this report).

(2) In the only tests in which the rise times of rapid loadings were varied (from 0.006 sec to 0.5 sec), the comparisons of delay time as defined by a stress parameter involving the upper yield point indicated no particular sensitivity to the rise time of loading within the limits indicated above. This result can probably be attributed to the manner in which the elapsed time to general yielding was arbitrarily defined (the interval between the time at which the stress first reached the nominal static upper yield stress level and that at which general

yielding occurred as indicated by a value of stress/strain equal to 20×10^6 psi).

(3) Within the range of rapidity of loadings applied, that is, rise times greater than 0.006 seconds, the value of Young's modulus was constant. The so-called strain hardening region also was relatively insensitive to time effects. The major time sensitivity was associated with initial yielding and subsequent general yielding, the so-called delayed yielding and rate of general yielding behaviors mentioned previously. For the high strength alloys of steel, and for 6061-T6 aluminum for which static stress-strain relationships having no discontinuity of slope were obtained, no delayed yielding or rate of general yielding behavior was evident.

(4) The results of the very few preliminary experiments in slow and rapid reversal of loading indicate that the so-called Bauschinger effect which is commonly observed in slow reversal of stress, is also present in cases involving rapid stress reversal with a consequent absence of delayed yield behavior commonly found in virgin material. Because of the type of specimen used in these preliminary studies, no conclusions could be reached regarding the rate of general yielding behavior.

3.5.2 General Significance of Results

As can be seen from the results described above, the increased resistance which results from the time sensitive behaviors of mild steel arbitrarily termed the delayed yielding and rate of general yielding phenomena can approach values 50 per cent greater than the nominal yield values even for the relatively slow rates of straining which may be created in frame type civil engineering structures in which the actual deformation of the major structural elements results from transfer of air blast or earthquake shock loading through the supports or outer shell.

In the case of many ship structures in which blast loading is applied directly, such as hull plating subjected to underwater explosion, the actual rates of straining can be many times greater than 1 in./in./sec. In these cases it is to be expected that resistances at least as great as the nominal static ultimate strength may be obtained without yielding or may be supported by the rate of deformation. Therefore, estimates of the response of these structural elements based upon nominal resistances derived from static yield values with no increase for the time sensitive effects will be very greatly in error. (The error, however, will be on the safe side unless brittle fracture or fatigue is a consideration.)

4. SLOW AND RAPID FLEXURE TESTS

4.1 Introduction

Structural components undergoing flexure such as beams, plates, and columns, are major elements of almost any structure. Therefore, it is logical, as an intermediate step between the uniaxial stress investigation and application of these results to the behavior of large full-size structures, that flexural stress studies be made of the same materials which were tested under uniaxial stress conditions. Such an investigation is described in this section of the report.

In all, three sets of specimens were tested. These included a preliminary series, BF, made from the semi-killed plate stock designated SPA and PS, a series, BK, made from fully-killed steel K, and a less completely instrumented series, BL, made from 6061-T6 aluminum L.

Each of the series was composed of four specimens, one of which was subjected to a slow loading, while the other three were tested under rapid loading to a constant level.

Since the materials from which the flexure specimens were composed was also tested under conditions of uniaxial stress, a correlation of the two stress conditions was attempted.

The purpose of this section of the report is to describe these flexure tests, the conditions under which they were run, the results and their engineering significance.

4.2 Description of the Flexure Testing Series

4.2.1 Description of Flexure Specimens

The flexure specimens in all cases were small beams of rectangular section approximately 24 in. long. The depth of the section was very close to

2 in., while the thickness or width varied from approximately 2/3 in. to approximately 7/8 in. The specimens were band-sawed from the parent plate, then machined in a shaper to very near the final dimensions. Following this, the outer surfaces of the specimen were draw-filed and hand polished to the final dimensions. All of the materials were tested in the as-rolled condition, and the only treatment of any sort that they received other then normal handling was that during the application of SR-4 gages they may have been subjected to prolonged heat of no more than 180 degrees F.

4.2.2 Material Properties Under Uniaxial Stress

As was mentioned in the introduction of this section, uniaxial stress tests were made of the materials from which the flexure specimens were composed. The stress-strain relationships, typical of those which were obtained for these materials are shown in Figs. 36a, 36d, and 36g. In addition to these results, the delayed yield behavior and the rate of general yielding behavior of the two mild steels are shown in Figs. 36b, 36c, 36e, and 36f.

4.3 Description of the Testing Procedures

4.3.1 Flexure Testing Arrangement

Both the slow and rapid loading tests were performed in the apparatus shown in Fig. 32. This is an attachment designed specifically to adapt the 20-kip pulse loading unit for these flexure tests. The loads are applied to the underside of the beam at the third-points, thereby deforming the beam upward as is shown in the figure. The only feature of the testing arrangement that may not be clear from the photographs is the end reaction system. The major bearings in the arrangement are roller bearing assemblies which are attached to the m chine frame by means of pins fixed on a 20-in. span. The reaction of the beam ends is transmitted to the outer race of the roller-bearing assembly through plates which are clamped to the

top and bottom of the beams by the bolts which are apparent in the figure. This end-reaction arrangement permits both translation and rotation at each end of the beam with the span length remaining fixed at 20 in. In other words, a change in length of the center line of the beam occurs during a test as the beam ends rotate and the beam deforms upward.

The loads which were applied to the specimen were measured by means of the two dynamometers visible in Fig. 32. The crossbar which can be seen in the photographs was provided to prevent flexure in the dynamometers.

4.3.2 Flexure Test Instrumentation

In these experiments measurements were made of the loads applied at the third-points of the beam, the acceleration of these loading points (except in the case of the aluminum specimens), the deflections at the third-points and at the center of the pure flexure region, and the strains on the outer fibers of the beam in the region of pure flexure. The relative locations of the loading points and the regions of strain measurement are shown in Fig. 34.

All phenomena were recorded on Hathaway magnetic oscillographs of the type mentioned in Section 3.3.1. The SR-4 gages used to measure the outer fiber strains on the specimen, and as the transducing elements in the dynamometers, were connected into four-arm bridge circuits as shown in Fig. 34. The accelerations were measured by means of an AMS-20A Hathaway accelerometer. It was fastened to the side of the loading beam as is evident in Fig. 32. The deflections were measured by means of the slide wire gages shown in the over-all view of the testing arrangement. The circuitry of the deflection measuring system is shown in Fig. 35.

Since two independent oscillographs were used for each test an interlocking timing system was necessary to permit correlation of the records. A timing

signal of 500 cps was recorded by one galvanometer in each oscillograph and the interlock was provided by a switch driven mechanically.

4.3.3 Description of Flexure Tests

As was mentioned in the introductory remarks, there were three series of flexure tests. The first of these was more or less preliminary in nature and, because of evident discrepancies, the results are somewhat questionable. This preliminary series, which has been designated BF, was composed of four tests. The first of these was run at a slow loading rate in the 20-kip pulse loading machine. In the other three, the loadings were applied in approximately 8 milliseconds after which a constant level was maintained until yielding had virtually ceased. Then the loading was released.

The second series designated BK, was tested using slightly different instrumentation. In an attempt to determine whether or not the distribution of strain throughout the depth of the beam section was linear, SR-4 gages were attached to the sides of the specimen at four depths through each half-depth of the beam. These gages may be clearly seen in Fig. 33. In addition, the curvatures in the region of pure flexure were determined for large deformations by means of spring steel curvature gages using SR-4 gages as the transducing elements. These were attached to the nominal center line of the beam on each side as is shown in Fig. 33. A different sensitivity was used in each of the two recording channels attached to the spring-steel curvature gages, so that the entire range of curvature was adequately defined. Deflections were measured only at the loading points in this particular series of tests. Again, as in the preliminary testing series, BF, the first test was performed at a slow rate. However, in this BK series the strain was controlled by means of a hydraulic jack attached to the lower end of the 20-kip pulse loading unit piston rod. This strain control resulted in a reasonably

constant rate of deformation throughout the duration of the test. The other three specimens of the BK series were tested with a load rapidly applied to a constant level. Three different levels of loads were used so that a range of possible delayed yield behavior and rate of general yielding behavior could be determined. Because of faulty film advance during the test of BK4, the records for this specimen were lost.

The last series of flexure specimens was composed of 6061-T6 aluminum. The instrumentation of this particular testing series included measurement of the loads at the third-points, the deflections at the loading points, the strain of the top and bottom fibers in the region of pure flexure, and the curvature in this same region. As with the other testing series, one test was performed slowly and the other three rapidly.

4.4 Results of Flexure Tests

4.4.1 Experimental Results of Flexure Tests

The data recorded in the three series of flexure tests are presented in Figs. 37, 38, and 39. The values of M_e and α_e for the flexural specimens are given in Figs. 36a, 36d, and 36g. Rate of curvature-time relationships for the rapid tests are also included since this information was obtained for use in computing the resisting moments for the sections.

It was planned to determine the resistance of a given beam by subtracting the inertia force as obtained from acceleration measurements at the loading point (and an assumed effective mass of the beam specimen system) from the applied load. However, the acceleration traces were not distinguishable in the region of initial loading. Therefore, the resistances were assumed to be the same as the applied load. The maximum error resulting from this approximation is estimated to be less than 2 per cent. Of course, for large deflections of the beam, a correction was

applied in determining resisting moment from the loads measured at the third-points of the beam.

The previously mentioned correction of resisting moment due to large deflections was made with the use of the loading point deflection gage information. The moment arm between the reaction and the loading point was increased by the factor secant ($\tan^{-1} m\Delta/6.67$); the reaction was taken as the dynamometer reading, a vertical force, increased by the same factor since the crossbar between the dynamometers produced a horizontal component of force acting at the loading points; and the moment arm was decreased by the factor tangent $\Delta/6.67$" since the loads were applied half the beam depth, or more, from the longitudinal centerline of the specimen. Actually, a more correct value for this latter factor was 1.8 times tangent $\Delta/6.67$" to account for the thickness of the loading blocks and the roller diameter. This larger correction would have decreased the indicated measured values of resisting moment ratio beyond $\alpha/\alpha_e = 30$ an additional 4 to 6 per cent with respect to what is now shown in Figs. 40a, 41a, and 42a.

Of primary interest to those concerned with the engineering behavior of materials subjected to flexure are the results presented in Figs. 40, 41, and 42. These are the relations between resisting moment and curvature obtained for the specimens tested. At any curvature the resistance obtained for the steel specimens tested rapidly was considerably larger than that obtained for the companion specimens tested slowly. This indicates that there is a time sensitivity associated with the behavior of mild steel in flexure.

In an earlier part of this report, Section 4.3.3, it was mentioned that the results of the RF Series were somewhat questionable since discrepancies were evident in the magnitudes of the measured resisting moments. These measured values were too high in the three regions which can be used for checking the data in both

slow and rapid tests; i.e., the elastic region ($\alpha/\alpha_e \leq 1$) where $M/M_e = \alpha/\alpha_e$, the general yield region ($1 \leq \alpha/\alpha_e \leq 10$) where M/M_e approaches 1.5, and the ultimate region ($\alpha/\alpha_e \cong 80$ for Series BF and BK) where $M/M_e = 1.5\ \sigma_m^*/\sigma_{1y}'' = 2.9$ in these cases. Re-examination of the original data indicated that the load values assigned to the calibration shunt resistor used with both of the dynamometer channels did not correspond to the load equivalences of the dynamometers at dynamometer strains equal to the apparent strain output of the shunt resistor. This check indicated that the load equivalence of the shunt resistor was 88 to 91 per cent of the shunt value used originally in reducing the data. The original data were therefore reduced by a factor of 0.91. The adjusted data, shown in Figs. 37a and 37e, were used for all subsequent computations pertaining to this test series. Since this change cannot be substantiated, except by noting the reasonable agreement in the three regions of curvature as detailed above, the BF Series results must be considered questionable.

The measured resistances of the rapidly loaded BK specimens, Fig. 41a, indicate that for the particular rise times of load (4 to 10 milliseconds) possible with the machine-specimen system used, an upper limit of resistance was obtained, at least until the work hardening range of curvatures was entered. Specimen BK-3 was subjected to a potential load some 30 per cent greater than was BK-2, yet only at a curvature ratio of about 40 could specimen BK-3 provide sufficient resistance to oppose the acting force.

Mild steel beams were definitely time sensitive; but, the results of the rapid flexure tests of the BL series indicated that there was little, if any, time sensitive behavior of the aluminum members subjected to flexure. The resisting moment-curvature relationship for specimen BF-4 is the only indication of an increase in resistance with the rapidity of deformation of an aluminum beam.

However, this result is questionable since the measured resistance did not agree as well with theory as could be expected in the elastic region, an indication of possible inaccuracies in measurement. Since aluminum coupons stressed uniaxially did not exhibit a time dependent behavior, the lack of such behavior in aluminum flexural specimens was expected.

4.4.2 Correlation Study

An attempt was made to correlate the behavior of these small mild steel beams under flexure with the known uniaxial stress properties of the materials from which the beams were made. In the correlation associated with the preliminary series BF, it was necessary to assume that the distribution of strain was linear throughout the depth of the beam section and that the material behaved the same in both tension and compression. For the next series, BK, it had been determined that these assumptions were valid. Therefore, proceeding from the measured strains of the beams, the resistances in the region of pure flexure were computed using the measured values of the instantaneous strains and the known delayed yielding and rate of general yielding behaviors of the materials from which the beams were made. (The procedure used for analyzing the rapidly loaded specimens is described in the Appendix.) In the case of the slowly deformed specimens, BF-1, BK-1, and BL-1, the material stress-strain curves as determined from slow straining coupon tests were used together with the measured strains of the beams.

The results of the correlation studies are shown in Figs. 40, 41, and 42. The measured resistance of BF-1 generally exceeded the computed resistance, but, the opposite was true for specimen BK-1. The failure of measured resistance to be as great as computed resistance has been noted by other investigators of the inelastic behavior of members. The discrepancy has been blamed in part on the severe stress concentrations associated with the application of concentrated loads

to the specimens. The measured resistance curves for specimens BK-1 and BL-1 exhibit a rising characteristic at large curvatures which probably resulted from an inadequate correction for large deflections.

Figures 40 and 41 show the correlation, correct to within 0 to 15 per cent, for the rapidly loaded specimens when their resistance is computed using the delay time-strain rate procedure. It may be noted that the use of strain rate information alone was insufficient to predict the maximum resistance of the specimen before major yielding began, but that this deficiency was satisfied by the inclusion of delay time considerations. Since no uniaxial time dependent properties of these materials deformed into the range of strain hardening were determined, the correlation was continued with respect to curvature using only the available rate of general yielding data until the rate of curvature approached zero. At this limit, the existing resisting stress is theoretically σ^*_{ly} and the resisting moment is 1.5 M_e. Actually, the beams had a much greater moment resisting capacity than these computations indicate, because the geometry of the specimen permitted strain hardening without local buckling.

The computations of the flexural resistance of the rapidly loaded beams described in this report agreed within an average of about 10 per cent with the measured resistance. However, the method of analysis presupposes the availability of the deformation-time function for the beam. In a practical problem the resistance and deformation functions, which are interrelated, are initially set arbitrarily before proceeding with the solution. Three common assumptions for beam resistance as a function of displacement are shown in Fig. 43. These are the following: (1) a resistance derived from a stress block (acting at any cross-section of the member) which is the elasto-plastic stress-strain curve for the beam material; (2) an elasto-plastic resistance function with an initial elastic slope

continued to the plastic moment ratio of $M/M_e = 1.5$; (3) an elasto-plastic resistance function with the initial elastic slope continued to a plastic moment ratio of something greater than 1.5 to account for the dynamic effects.

If the measured resistance of the rapidly loaded mild steel beams is interpreted in terms of the arbitrary resistance functions described above, the third method would most adequately predict the observed behavior if the fully plastic resistance is increased by 60 per cent for BF-2 and 40 per cent for BF-3 (probably high due to the questionably high dynamometer data), and 40 per cent for BK-2 and BK-3.

4.5 Summary of Results of Flexure Tests

4.5.1 Summary of Results

The major purpose of the flexure tests was to determine whether or not the resistance of material in flexure could be correlated with the stress-strain-time information obtained in slow and rapid uniaxial stress tests. Therefore, the results of the flexure tests are interpreted in such a manner that this comparison is relatively simple. Basic data which are representative of slow and rapid tests of each of the three materials tested are shown in Figs. 36. In Figures 40a, 41a, and 42a moment curvature relationships obtained from all of the flexure tests are shown.

As was mentioned earlier, the major purpose of the flexure tests was to determine whether or not the behavior of materials when subjected to slow and rapid flexure could be correlated with the behavior (as obtained from slow and rapid uniaxial stress tests) of the materials from which the beams were made. Therefore, the major result of the flexural test investigation is the comparison of beam resistances as determined from measured deformations of the beam specimens and knowledge of material properties with the behavior of the beams as measured directly

in each test. These comparisons are shown for each specimen in Figs. 40, 41, and 42, in which is presented (1) the measured moment curvature relationships, (2) the moment curvature relationship determined using measured deformation of the beam and material properties determined from slow and rapid uniaxial stress tests, and (3) the moment curvature relationship representing the elasto-plastic strain relationship which best represents the basic stress-strain relationship of the specimen material as obtained with slow straining rates. This comparison indicates that the behavior of the material under flexure can be explained within less than 10 per cent error by consideration of material properties as obtained in uniaxial stress tests. This explanation is in almost all cases more accurate than the commonly used elasto-plastic assumption.

4.5.2 <u>Significance of Results</u>

The results of the flexure tests have been correlated (within reasonable limits) with the uniaxial stress properties of the material from which the beams were made. This indicates that it should be possible to progress from the current knowledge of the behavior of structural metals under slow and rapid uniaxial stress to an explanation of the behavior of structures composed of elements such as beams, beam-columns, and medium thick plates when subjected to transient dynamic loadings producing extensive inelastic deformations.

5. GENERAL SUMMARY

5.1 General Summary

As was mentioned in the introduction of this report the primary purposes of the investigation were to determine the time sensitive stress deformation characteristics of several of the more commonly used structural metals, and to determine the engineering significance of this information as regards application in the solution of problems concerned with the behavior of metal structures when subjected to transient dynamic loads producing extensive inelastic deformation.

The work that has been done has included many tests of several of the more commonly used structural metals including mild steels of the rimmed, semi-killed, and fully-killed varieties as obtained from plate, bar, and rolled section stocks; a few of the commonly used alloys of steel; and one very commonly used structural aluminum. The tests have included slow and rapid applications of stress under uniaxial conditions and conditions of pure flexure. In addition, a very few reversed loadings were applied to one material.

The results indicate that in general those materials which have a pronounced upper lower yield point phenomena in slow straining rate tests (that is, a discontinuity in slope of the stress-strain relationship) also exhibit a time sensitive behavior in the region from initial inelasticity through general yielding, and a less significant time sensitive behavior in the region of strain hardening. The so-called elastic region is apparently insensitive to time effects for loadings applied in times no more rapid than a few milliseconds. The results pertaining to the time sensitivity where present have been arbitrarily presented in the form of delayed yield and rate of general yielding information. The results of the tests of materials which were not very time sensitive were presented in the form of

stress-strain and strain-time relationships, and in a few cases, as elapsed times to specific amounts of yielding as defined by various arbitrary selected values of the secant moduli (stress/strain).

A major purpose of the investigation, as was mentioned above, was to provide information which would indicate whether or not the results of uniaxial stress tests could be extended to flexural stress conditions. The results of the flexure tests which were performed in this investigation indicate that this can be done with less than 10 per cent error.

Therefore, in many cases it should be possible to apply the results of uniaxial stress tests in predicting the response of frame and plate type structures to transient dynamic loadings that produce extensive inelastic deformation.

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APPENDIX

DETERMINATION OF FLEXURAL RESISTANCE FROM BEAM DEFORMATION AND UNIAXIAL STRESS PROPERTIES

As was mentioned in Section 4.4.2 the resisting moment corresponding to the curvature measured in the region of pure flexure was determined by computation using the deformation as determined either from SR-4 gages on the outer fiber of the beam or from the curvature gages applied to the sides of the beam, and three assumptions: (a) that the distribution of strain is linear through the depth of the beam section; (b) that the behavior of the beam material used is the same in both tension and compression; and (c) that the materials information obtained under conditions of uniaxial stress can be applied to the stress gradient conditions existing in the beam.

For single load applications, stress in mild steel is a single valued function of strain. Therefore, the procedure used in computing resisting moment from measured strains is straightforward. It consists of determining the strain distribution in the beam section at the time considered, finding the corresponding stress distribution by use of the comparable stress-strain relationship for the beam material, and computing the resisting moment from the stress distribution and consideration of the geometric properties of the beam section.

For the rapid tests, the procedure used to determine the resisting moment of a specimen section from the measured outer fiber strain or the strain as determined from the curvature gage is complicated by the fact that, under conditions of rapid loading, stress in the material is a function of not only strain, but also strain rate and time. However, by making one other major assumption in addition to those listed above, the desired resisting moment can be obtained. That assumption

is (d) that the stress-time characteristics of the beam material determined from the materials studied under a stress-time relationship that is applied rapidly and is thereafter maintained constant are applicable to the stress-time conditions probably existing in the beam specimens. (The validity of this assumption can be checked later by comparing the stress-time relationship computed for a given fiber in the beam with the stress-time function with which the materials were tested.)

The procedure used for determining the instantaneous resistance of the beam section to an imposed measured straining is described in the following paragraph. This procedure requires the use of the measured strain-time information obtained for the beam section considered, and information similar to that contained in Figs. A1 and A2, which represent the inelastic time dependent and strain rate dependent behavior of one of the beam materials used.

By using the measured beam deformation as determined either from the SR-4 gages on the outer fiber or the curvature gage applied to the sides of the beam in conjunction with the information of Fig. A2, the times at which the various values of apparent modulus were reached could be determined as is shown in Fig. A3*. For each of those times the stress on the outer fiber could then be computed ($\sigma = \epsilon \cdot \sigma/\epsilon$) so that the stress-time history was known for the particular fiber considered from the initial straining through straining corresponding to σ/ϵ = 20×10^6 psi (Fig. A3). For strains beyond this value it was assumed that the instantaneous stress level could be determined from the measured strain rate through use of Fig. A2b. In this manner the stress-time relationship was determined for the particular fiber of the beam considered. This, of course, could be done for as many fibers through the depth of the section as desired (assuming that the

* The strain-delay time overlay used in Fig. A3 may be constructed from Fig. A2a since strain as well as stress may be related to delay time by means of the relationship σ/ϵ.

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distribution of strain is linear with depth) so that instantaneous stress "blocks" and, in turn, instantaneous section resistances could be computed. For the BF and BL series flexure specimens the stress blocks were determined by consideration of strains at six locations through the half depth of the section. For the BK series specimens, in which four SR-4 gages were positioned through each half depth of the beam, a correlation of measured strains was made with the assumed linear distribution of strain mentioned in Section 4.4.2. This comparison indicated that the distribution of strain with depth was virtually linear. Therefore, as many individual strains were computed through the half depth of the beam for the BK specimens as were computed for the other flexure tests.

No "elapsed time to $\sigma/\epsilon = 30 \times 10^6$ psi" data for the BK material were available since no SR-4 strain gages were applied to the coupons and the extensometer was not capable of indicating the time at which the secant modulus first departed from a value of 30×10^6 psi. Therefore, in the analysis of this series of specimens the delay for time for $\sigma/\epsilon = 30 \times 10^6$ psi was taken as zero.

TABLE 1

SUMMARY OF UNIAXIAL TESTING PROGRAM

Series	Type of Material (As rolled and as machined except where noted)	Manner of Testing			
		Slow			Rapid
		Loaded	Strained	Cycled	Loaded
RB	Rimmed steel, ASTM A7	X	X	X	X
	Polished	X	X	X	X
	Notched		X		X
	Polished and annealed		X		X
	Notched and annealed				
SP	Semi-killed steel, ASTM A7				
	Polished	X	X	X	X
	Notched		X		X
	Polished and annealed		X		X
	Notched and annealed		X		X
NB	ASTM A7 steel	X	X		X
NR	ASTM A7 steel, annealed		X		X
NN	Low alloy steel		X		X
NL	Low alloy steel	X	X		X
NTY	Nickle-chromium steel		X		X
[illegible]	Semi-killed steel, ASTM A7		X		X
K	Fully-killed steel, ASTM A7		X		X
Q	Low alloy steel, ASTM A242		X		X
T	USS T-1 steel		X		X
A,B	ASTM A7 steel, from rolled 4M section		X		X
L	6061-T6 structural aluminum		X		X

TABLE 2

UNIAXIAL SPECIMEN DESIGNATION CODE

Series RB, SP (Profile Fig. 9)

The numbers or letters in "digit" order are:

1. Specimen Area
   - 1 = 0.100 sq.in. = 0.357 in. D.
   - 2 = 0.200 sq.in. = 0.505 in. D.
2. Specimen Surface
   - S = Polished smooth (to about 15 μ in. r.m.s.)
   - M = As Machined (Surface roughness is about 150 μin. r.m.s.)
   - N = Polished then notched about 0.01 in. deep
3. Type of Steel
   - R = Rimmed steel
   - S = Semi-killed steel
4. Stock Form of Metal
   - B = Hot rolled bar
   - P = Hot rolled plate
5. Treatment
   - A = As rolled
   - B = Annealed and spheroidized after machining (in Helium atmosphere)
     - 2 1/2 hours at 1690°F.
     - 25 hours at 1330°F.
   - C = Annealed and spheroidized before machining (in Helium atmosphere)
     - 2 3/4 hours at 1690°F.
     - 25 hours at 1310°F.
6. Identical Specimen Number
   - 1 = first specimen of the type, etc.

<u>Example</u>: Specimen 1SRBA2 is a 0.357 in. D. polished specimen of rimmed steel obtained from hot rolled bar stock left as rolled and is the second specimen of this type.

Series NW, NB (Profile Fig. 11)
NL, NHY (Profile Fig. 9)
NR (Profile Fig. 12)
PB (Profile Fig. 13)

The series designation is suffixed to indicate the orientation of the coupon with respect to the direction of mill rolling of the parent material.

- L = Longitudinal
- T = Transverse

Series K, Q, T, L (Profile Fig. 13)

No suffix precedes or follows specimen number.

Series PBL-A, K-A (Profile Fig. 13)

- A = Reduced gage section over full length of the specimen between threads

TABLE 3 RESULTS OF METALLURGICAL STUDIES

Steel Designation	Specimen Studied	Steel Stock and Treatment	Rockwell "B" Hardness[1] Surface	Center[2]	Decarburization	Microstructure	A.S.T.M. Grain Size
RBA	1SRBA4	Rimmed Steel, Hot rolled 1" φ bar As rolled	73	80	---	Fine pearlite in an α matrix Some banding, showing slight directional properties	7
RBB	1RRBB2	Rimmed Steel Hot rolled 1" φ bar Annealed, spheroidized[3]	47	66	Surface Decarburized 0.015 to 0.020 inches deep	Coarse pearlite in an α matrix Extensive spheroidization of Fe_3C	-
RBC	1SRBC4	Rimmed Steel Hot rolled 1" φ bar Annealed, spheroidized[4]	62	72	No decarburization	Both coarse and fine pearlite in an α matrix. Some spheroidization of Fe_3C	-
SPA	1RSPA4	Semi-killed Steel Hot rolled 1" plate As rolled	69	79	---	Fine pearlite in an α matrix Little or no directional properties	5
SPB	1RSPB2	Semi-killed Steel Hot rolled 1" plate Annealed, spheroidized[3]	58	66	No decarburization	Both fine and coarse pearlite in an α matrix. Some spheroidization of Fe_3C in the pearlite.	-
HS	T4	Hot rolled 14 gage As rolled	58	45[5]	Decarburized total thickness of sheet	A few coarse Fe_3C particles in an α matrix. Some MnS inclusions in center.	-
HR	R2	Hot rolled 1" plate Annealed, exact treatment unknown.	61	78	Decarburized in banded zones	Banded fine pearlite in an α matrix. Strongly directional properties.	-

1 Average of three readings
2 Readings taken on center of section used for metallurgical studies
3 Treated after machining but before polishing final 0.069 in. - 2 1/2 hr. at 1690°F., 23 hr. at 1330°F.
4 Treated before machining - 2 3/4 hr. at 1690°F., 25 hr. at 1310°F.
5 Specimen section was narrow and some yielding to sides may have occurred.

TABLE 4 CHEMICAL COMPOSITIONS OF SPECIMEN STEELS

Series	Specimen Checked	Description	C	Mn	P	S	Si	Cu	Ni	Cr	N	Al	Mo	V
			Chemical Composition (Check Analysis)											
RDA	2SRBA28	Rimmed steel Hot rolled, 1" φ bar	0.19	0.35	0.021	0.052	0.01	--	--	--	0.014	--	--	--
SPA	2S3PAL11	Semi-killed steel Hot rolled, 1" plate	0.27	0.51	0.033	0.036	0.05	--	--	--	0.013	--	--	--
NC	14	Hot rolled 14 gage sheet	0.05	0.40	0.036	0.018	0.01	-	--	--	0.013	--	--	--
NR	R5	Hot rolled 1" plate Annealed	0.34	[illegible]	0.025	0.032	0.02	--	--	--	0.013	--	--	--
NN	N111	Hot rolled 5/16" plate Low alloy	0.18	1.01	0.042	0.039	[illegible]	0.10	None	0.11	[illegible]	--	--	--
NL	LT1	Hot rolled 1" plate Low alloy	0.16	1.11	0.027	0.029	0.23	0.33	None	0.13	0.016	--	--	--
NHY	NHYL2		0.13	0.19	0.006	0.011	0.05	none	2.32	1.34	0.010	--	--	--
Q		Hot rolled 3/4" plate ASTM A-242	0.19	1.10	0.022	0.028	0.25	0.45	None	None	--	--	--	0.04
T		Hot rolled 3/4" plate U.S. steel "T-1"	0.11	0.84	0.036	0.015	0.30	0.32	0.99	0.50	--	0.09	0.55	0.095
K	*	Hot rolled 3/4" plate Fully killed steel	0.15	0.87	0.11	0.034	0.16	--	--	--	--	--	--	--

*Ladle Analysis

TABLE 5a SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	**Rise time of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{m} - \sigma^*_{uy}}$	***Time to Start Strain yield Milliseconds	**Time to σ/c = 20 ksi Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{m} - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
ISRBA1	Slow $\dot{\epsilon} = C_2$	Baldwin		150	49.4	37.4	65.2	57	34	0.08						
2	Rapid to $\sigma = C_1$	Pulse Ldg	0.9	0.006	52.8					0.15	0.42	88	113			
3	Slow $\dot{\epsilon} = C_2$	Baldwin		200	45.2*	37.0*	62.4*	62	40	0.00						
4	Rapid to $\sigma = C_1$	Pulse Ldg	5.4	0.006	57.4					0.25	0.70	31	42			
INRBB1	Slow $\dot{\epsilon} = C_2$	Baldwin		80	26.8	21.5	53.8	42	35	0.10						
2	Rapid to $\sigma = C_1$	Pulse Ldg	3.3	0.006	27.9					0.14	0.12	1600				
3	Slow $\dot{\epsilon} = C_2$	Baldwin		80	24.3*	21.6*	54.0*	51	33	0.00						
4	Rapid to $\sigma = C_1$	Pulse Ldg	3.2	0.006	27.2					0.11	0.09	9000				
ISRBC1	Slow $\dot{\epsilon} = C_2$	Baldwin		60	26.0	25.0	50.3	47	34	0.00						
2	Rapid to $\sigma = C_1$	Pulse Ldg	1.6	0.006	31.4					0.21	0.17	240	368			
3	Slow $\dot{\epsilon} = C_2$	Baldwin		80	26.0*	23.4*	57.5*	47	31	0.00						
4	Rapid to $\sigma = C_1$	Pulse Ldg	5.3	0.006	43.0					0.66	0.53	3	12			
INRBA1	Slow $\dot{\epsilon} = C_2$	Baldwin		200	42.9*	35.5*	62.9*	38	36	0.00						
2	Rapid to $\sigma = C_1$	Pulse Ldg	4.0	0.006	53.0					0.23	0.50	16	38			
3	Slow $\dot{\epsilon} = C_2$	Baldwin		200	46.2	36.2	62.3	37	35	0.08						
4	Rapid to $\sigma = C_1$	Pulse Ldg	4.8	0.006	60.8					0.42	0.90	10	19			
INRBB1	Slow $\dot{\epsilon} = C_2$	Baldwin		160	25.8*	22.4*	54.1*	49	39	0.00						
2	Rapid to $\sigma = C_1$	Pulse Ldg	9.7	0.006	31.8					0.23	0.21	108	212			
3	Slow $\dot{\epsilon} = C_2$	Baldwin		160	26.2	21.4	54.6	47	36	0.02						
4	Rapid to $\sigma = C_1$	Pulse Ldg	8.5	0.006	44.5					0.72	0.66	3	12			

*Basic value used in stress parameter

**Time over static upper yield stress, $\dot{\sigma}_{uy}$

***Extensometer point marks on gage section

TABLE 5b SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Loading, f	**Rise time of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma_c - \sigma^*_{uy}}$	***Time to SRL strain yield Milliseconds	Time to $\varepsilon/\dot{\varepsilon}$ = 20 Msi Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma_c - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
ISSPA1	Slow $\dot{\varepsilon}$ = C	Baldwin		110	38.2	34.5	67.0	54	34	0.02						
2	Rapid to $\sigma = C_1$	Pulse Ldg	2.4	0.006	43.4					0.16	0.22	132	165			
3	Slow $\dot{\varepsilon}$ = C	Baldwin		250	37.5*	33.4*	63.7*	60	40	0.00						
4	Rapid to $\sigma = C_1$	Pulse Ldg	2.4	0.006	54.7					0.46	0.66	0	8			
IBBPB1	Slow $\dot{\varepsilon}$ = C	Baldwin		180	29.1	25.4	60.3	43	38	0.06						
2	Rapid to $\sigma = C_1$	Pulse Ldg	1.5	0.006	35.0					0.25	0.19	88	125			
3	Slow $\dot{\varepsilon}$ = C	Baldwin		170	27.4*	24.4*	60.4*	44	36	0.00						
4	Rapid to $\sigma = C_1$	Pulse Ldg	0.8	0.006	47.0					0.74	0.61	0	8			
IBBPA1	Slow $\dot{\varepsilon}$ = C	Baldwin		100	32.0*		64.7*	51	34	0.00						
2	Rapid to $\sigma = C_1$	Pulse Ldg	0.4	0.006	43.4					0.36	0.35	44	88			
3	Slow $\dot{\varepsilon}$ = C	Baldwin		100	31.6	33.4	64.2	57	37	0.21						
4	Rapid to $\sigma = C_1$	Pulse Ldg	1.5	0.006	51.6					0.61	0.60	2	11			
IBBPH1	Slow $\dot{\varepsilon}$ = C	Baldwin		200	29.2	25.2	57.4	35	34	0.11						
2	Rapid to $\sigma = C_1$	Pulse Ldg	1.5	0.006	35.0					0.34	0.26	72	133			
3	Slow $\dot{\varepsilon}$ = C	Baldwin		200	26.2*	24.4*	59.5*	38	34	0.00						
4	Rapid to $\sigma = C_1$	Pulse Ldg	0.4	0.006	44.4					0.69	0.55	3	11			

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5c SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	Pulse time** or load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma_n - \sigma^*_{uy}}$	***Time to 5% Strain yield Milliseconds	**Time to σ/c = 20 ksi Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_n - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
[illegible] 1	Slow	Pulse Ldg	2.[illegible]	1[illegible]	52.6					0.08	0.27	4500	—	0.40	0.59	0.065
2	Rapid to σ = C	Pulse Ldg	3.2	0.006	51.5					0.06	0.19	1440	1575	0.37	0.54	0.15
3	Rapid to σ = C	Pulse Ldg	3.4	0.006	54.2					0.11	0.38	310	322	0.44	0.65	0.66
4	Rapid to σ = C	Pulse Ldg	1.[illegible]	0.006	56.8					0.17	0.56	85	87	0.51	0.75	1.08
5	Rapid to σ = C	Pulse Ldg	0.0	0.006	[illegible].7					0.25	0.76	15	33	0.59	0.86	[illegible]
6	Rapid to σ = C	Pulse Ldg	1.8	0.160	[illegible].4					0.05	0.12	1050	1077	0.34	0.50	0.15
7	Rapid to σ = C	Pulse Ldg	4.4	0.154	51.[illegible]					0.07	0.22	174	211	0.38	0.56	0.44
8	Rapid to σ = C	Pulse Ldg	0.[illegible]	0.155	56.4					0.16	0.55	115	134	0.50	0.74	1.10
9	Rapid to σ = C	Pulse Ldg	10.4	0.120	56.7					0.16	0.55	80	98	0.51	0.75	1.37
10***	Slow $\dot{\epsilon} = C_1$	Baldwin	2.7	[illegible]	43.1	37.5*	62.5	58	39	0.1[illegible]	0.39			0.00	0.00	0.00020
11	Rapid to σ = C	Pulse Ldg	0.6	0.742	52.2					0.07	0.24	3600	3708	0.39	0.57	0.15
12	Rapid to σ = C	Pulse Ldg	4.2	0.677	55.0					0.03	0.50	445	501	0.41	0.60	0.17
13	Rapid to σ = C	Pulse Ldg	0.0	0.560	55.5					0.14	0.47	380	404	0.48	0.70	0.59
14	Rapid to σ = C	Pulse Ldg	2.5	0.370	56.1					0.15	0.51	195	225	0.50	0.72	0.85
15	Slow	Pulse Ldg	0.6	17.8	51.5					0.06	0.19	3200		0.37	0.54	0.11
16	Slow	Pulse Ldg	2.5	21.5	52.2					0.07	0.24	2000		0.39	0.57	0.082
17	Cycled	Pulse Ldg	2.5		50.0					0.05						
18	Cycled	Baldwin	4.3		43.7*	35.0	63.8*	61	40							
[illegible] 19	Cycled	Riehle	7.2		46.8	35.1	62.2	61	39	0.04	0.13					

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5d SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	*Rise time* of load, sec.	Nominal Stress, ksi σ_{uy}	σ_{ly}	σ_{max}	Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_m - \sigma^*_{uy}}$	**Time to SR-4 Strain yield Milliseconds	**Time to σ/ϵ = 20 Msi Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_m - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
2SRBA 1	Cycled	Pulse Ldg	2.1		50.2					0.00						
2	Rapid to $\sigma = C_1$	Pulse Ldg	0.3	0.006	56.9					0.14	0.50	1165	1212	0.46	0.74	0.14
3	Rapid to $\sigma = C_1$	Pulse Ldg	1.0	0.006	56.8					0.14	0.50	715	746	0.46	0.74	0.21
4	Rapid to $\sigma = C_1$	Pulse Ldg	5.7	0.006	56.9					0.14	0.50	775	709	0.46	0.74	0.24
5	Rapid to $\sigma = C_1$	Pulse Ldg	2.6	0.006	59.2					0.18	0.68	105	165	0.52	0.85	0.67
6	Rapid to $\sigma = C_1$	Pulse Ldg	3.8	0.20	54.4					0.09	0.32	1440	2230	0.39	0.64	0.18
7	Rapid to $\sigma = C_1$	Pulse Ldg	0.0	0.15	54.6					0.09	0.33	780	392	0.40	0.64	0.15
8	Rapid to $\sigma = C_1$	Pulse Ldg	0.0	0.14	57.2					0.14	0.53	250	974	0.47	0.75	0.47
9	Rapid to $\sigma = C_1$	Pulse Ldg	1.8	0.15	59.4					0.19	0.69	240	287	0.52	0.84	0.67
10***	Slow $\epsilon = C_2$	Baldwin	11.5	90	44.6	40.1	63.9	60	40	-0.11				0.05	0.04	0.00026
11	Rapid to $\sigma = C_1$	Pulse Ldg	3.8	0.80	53.1					0.06	0.22	750	767	0.36	0.59	0.072
12	Rapid to $\sigma = C_1$	Pulse Ldg	4.6	10	53.3					0.07	0.25	4075	4150	0.37	0.59	0.12
13	Rapid to $\sigma = C_1$	Pulse Ldg	3.0	0.70	56.0					0.12	0.44	1000	1028	0.44	0.70	0.21
14	Rapid to $\sigma = C_1$	Pulse Ldg	4.5	0.70	57.8					0.16	0.57	580	692	0.48	0.78	0.24
15	Slow $\dot{\sigma} \neq C$	Pulse Ldg	5.7	20.5	53.8					0.08	0.27	4000		0.38	0.61	0.076
16	Slow $\dot{\sigma} = C$	Pulse Ldg	1.8	30.0	54.2					0.08	0.30	15000		0.39	0.63	0.045
17	Slow Increment	Pulse Ldg	2.5	22.0	48.3					-0.03				0.24	0.38	0.011
18	Slow Increment	Pulse Ldg	1.9	60+	53.1					0.06	0.22	4 min		0.36	0.58	0.042
2SRBA19	Slow Increment	Pulse Ldg	0.7	60+	53.6					0.07	0.26	3 min		0.37	0.60	0.029

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5a SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	*Rise time* of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma_c - \sigma^*_{uy}}$	***Time to SRL Strain yield Milliseconds	**Time to σ/c = 20 ksi Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma_c - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
2SRPA20	Rapid to $\sigma = C_1$	Pulse Ldg	1.6	0.006	56.5					0.15	0.47	565	621	0.45	0.72	0.27
21	Rapid to $\sigma = C_1$	Pulse Ldg	4.7	0.006	58.4					0.18	0.65	110	130	0.51	0.82	0.65
22	Rapid to $\sigma = C_1$	Pulse Ldg	0.8	0.006	61.2					0.22	0.85	120	131	0.57	0.92	1.17
23	Rapid to $\sigma = C_1$	Pulse Ldg	3.6	0.006	60.2					0.20	0.77	125	155	0.54	0.88	1.85
24	Rapid to $\sigma = C_1$	Pulse Ldg	1.5	0.12	56.0					[illegible]	0.44	1050	1075	0.44	0.70	0.24
25	Rapid to $\sigma = C_1$	Pulse Ldg	1.6	0.12	57.[illegible]					0.15	0.56	85	94	0.46	0.77	0.[illegible]
26	Rapid to $\sigma = C_1$	Pulse Ldg	1.3	0.13	60.5					0.21	0.77	125	143	0.55	0.89	1.10
27	Rapid to $\sigma = C_1$	Pulse Ldg	1.3	0.12	60.4					0.21	0.77	150	172	0.55	0.80	1.14
28***	Slow $\dot{\epsilon} = C_2$	Baldwin	2.5	89	45.6	39.0	65.5	61	36	-0.11				0.00	0.00	0.00015
29	Rapid to $\sigma = C_1$	Pulse Ldg	1.4	0.35	56.0					0.12	0.44	500	455	0.44	0.70	0.32
30	Rapid to $\sigma = C_1$	Pulse Ldg	1.1	0.39	56.8					0.14	0.50	220	233	0.46	0.74	0.67
31	Rapid to $\sigma = C_1$	Pulse Ldg	0.6	0.35	57.4					0.15	0.56	180	184	0.47	0.76	0.62
32	Rapid to $\sigma = C_1$	Pulse Ldg	1.2	0.31	58.2					0.16	0.60	140	154	0.49	0.79	1.05
33	Slow $\dot{\epsilon}$ & $\dot{\sigma}$ C	Pulse Ldg	1.2	26	52.2					0.04	0.15	2500		0.34	0.54	0.085
34	Slow $\dot{\epsilon}$ & $\dot{\sigma}$ C	Pulse Ldg	0.0	16	51.5					0.03	0.10	1000		0.32	0.52	0.064
35	Cycled	Pulse Ldg	4.6		50.0					0.0						
2SRPA36	Cycled	Baldwin	[illegible]		50.2*	37.0	65.2*	61	30	[illegible]						

*Basic value used in stress parameter
**Time over static upper yield stress, σ^*_{uy}
***Extensometer point marks on gage section

TABLE 5C SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	**Rise time of load, sec.	Nominal Stress, ksi σ_{uy}	σ_{ly}	σ_{max}	Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy}-\sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy}-\sigma^*_{uy}}{\sigma^*_m-\sigma^*_{uy}}$	Time to SRL Strain Yield, Milliseconds	Time to $\dot{\sigma}/t$ = 20 Msi Milliseconds	$\frac{\sigma_{ly}-\sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly}-\sigma^*_{ly}}{\sigma^*_m-\sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
2GSPAL1	Cycled	Riehle	4.3		37.0	31.5	63.9	56	43	-0.01						
2	Rapid to $\sigma = C_1$	Pulse Ldg	1.7	0.006	44.6					0.19	0.26	125	145	0.36	0.37	0.17
3	Rapid to $\sigma = C_1$	Pulse Ldg	4.5	0.006	50.9					0.36	0.47	12	21	0.56	0.57	1.87
4	Rapid to $\sigma = C_1$	Pulse Ldg	5.6	0.006	56.1					0.50	0.68	2	3	0.72	0.73	5.27
5	Rapid to $\sigma = C_1$	Pulse Ldg	7.4	0.006	40.0					0.07	0.09	370	453	0.22	0.23	0.068
6	Rapid to $\sigma = C_1$	Pulse Ldg	2.5	0.14	41.[illegible]					0.12	0.16	270	365	0.28	0.29	0.042
7	Rapid to $\sigma = C_1$	Pulse Ldg	2.2	0.13	46.1					0.23	0.32	10[illegible]	130	0.4[illegible]	0.42	0.32
8	Rapid to $\sigma = C_1$	Pulse Ldg	1.8	0.0[illegible]	48.[illegible]					0.30	0.42	65	67	0.50	0.51	0.45
9	Rapid to $\sigma = C_1$	Pulse Ldg	0.9	0.13	40.4					0.08	0.11	850	926	0.24	0.24	0.016
10	Slow $\dot{\epsilon} = C_2$	Pulse Ldg	4.1	20	38.7					0.05	0.04	6500		0.18	0.19	0.0065
11***	Slow $\dot{\epsilon} = C_2$	Baldwin	4.8	5[illegible]	38.7	32.7*	64.5	56	36	0.02	0.04	2000		0.00	0.00	0.0002
12	Rapid to $\sigma = C_1$	Pulse Ldg	4.6	0.60	41.6					0.11	0.15	450	477	0.27	0.28	0.045
13	Rapid to $\sigma = C_1$	Pulse Ldg	0.0	0.40	44.8					0.19	0.27	250	268	0.37	0.38	0.34
14	Rapid to $\sigma = C_1$	Pulse Ldg	5.2	0.26	46.4					0.24	0.32	140	146	0.42	0.43	0.53
15	Rapid to $\sigma = C_1$	Pulse Ldg	2.9	0.60	40.8					0.09	0.12	1100	1140	0.25	0.25	0.020
16	Cycled	Pulse Ldg	5.8		37.2					-0.01						
2GSPAL17	Cycled	Baldwin	4.7		37.5*	34.5	64.7*	56	34	0.00						

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5a SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	[illegible]	Pulse Time of Load, sec.	Nominal Stress, ksi σ_{uy}	σ_{ly}	σ_{max}	Reduction in Area, %	Elongation in 2 in. Gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	[illegible]	Time to [illegible] Strain Yield, milliseconds	Time to [illegible] 20 Ms, milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	[illegible]	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
2SSPAT 1	Cycled	Pulse Ldg	1.5		38.4					0.00	0.00					
2	Rapid to $\sigma = C_1$	Pulse Ldg	4.5	0.006	40.6					0.06	0.08	520	501	0.16	0.18	0.031
3	Rapid to $\sigma = C_1$	Pulse Ldg	1.1	0.006	45.0					0.17	0.24	125	136	0.27	0.32	0.38
4	Rapid to $\sigma = C_1$	Pulse Ldg	0.1	0.006	49.4					0.28	0.40	20	33	0.41	0.46	1.60
5	Rapid to $\sigma = C_1$	Pulse Ldg	4.0	0.006	55.2					0.32	0.24	5	10	0.52	0.58	4.46
6	Rapid to $\sigma = C_1$	Pulse Ldg	0.0	0.12	41.0					0.07	0.10	1210	1254	0.1[illegible]	0.1[illegible]	0.025
7	Rapid to $\sigma = C_1$	Pulse Ldg	3.1	0.15	41.6					0.08	0.12	340	347	0.1[illegible]	0.21	0.025
8	Rapid to $\sigma = C_1$	Pulse Ldg	3.2	0.11	45.6					0.13	0.20	85	25	0.30	0.34	0.27
9	Rapid to $\sigma = C_1$	Pulse Ldg	3.5	0.0[illegible]0	48.5					0.20	0.37	45	33	0.31	0.43	1.30
10	Slow $\dot{\epsilon} = C$	Pulse Ldg	0.0	16	38.5					0.00	0.06	4000		0.10	0.11	0.0078
11***	Slow $\dot{\epsilon} = C_2$	Baldwin	0.0	48	38.2*	39.0*	60.2*	45	38	0.00	0.00			0.00	0.00	0.00019
12	Rapid to $\sigma = C_1$	Pulse Ldg	0.0	0.54	40.2					0.05	0.07	400	617	0.15	0.22	0.052
13	Rapid to $\sigma = C_1$	Pulse Ldg	1.0	0.77	41.5					0.08	0.12	445	540	0.17	0.21	0.076
14	Rapid to $\sigma = C_1$	Pulse Ldg	3.7	0.35	45.3					0.14	0.20	170	202	0.25	0.23	0.25
2SSPAT15	Rapid to $\sigma = C_1$	Pulse Ldg	2.6	0.26	45.7					0.19	0.27	115	155	0.31	0.34	0.31

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5b SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	[illegible]	[illegible]	Nominal Stress, ksi σ_{uy}	σ [illegible]	σ [illegible]	Reduction in Area, %	Elongation in [illegible], %	[illegible]	[illegible]	Time to Yield, milliseconds	[illegible] milliseconds	[illegible]	[illegible]	[illegible] yield [illegible]
NST 9	Slow $\dot{\epsilon}$ = C_2	Baldwin	6.5	100	[illegible]*	56.1*	[illegible]**	[illegible]		0.00						
10	Rapid to σ = C	Pulse Ldg	[illegible]	0.006	45.[illegible]					0.1[illegible]	0.6[illegible]	500	[illegible]			
11	Rapid to σ = C	Pulse Ldg	[illegible]	0.006	42.[illegible]					0.1[illegible]	0.97	11.0	[illegible]			
12	Rapid to σ = C	Pulse Ldg	[illegible]	0.006	[illegible]					0.[illegible]	1.04	[illegible]	[illegible]			
13	Rapid to σ = C	Pulse Ldg	[illegible]	0.006	47.[illegible]					0.2[illegible]	1.10	70	115			
NST 14	Slow σ ≠ C	Pulse Ldg	[illegible]	100	45.6					[illegible]	[illegible].67					
NSL 20	Slow $\dot{\epsilon}$ = C_2	Baldwin	1[illegible]	20	3[illegible].6*	35.5*	46.1*	6[illegible]		0.00						
21	Rapid to σ = C	Pulse Ldg	[illegible]	0.006	37.[illegible]					0.09	0.2[illegible]	[illegible]60	11[illegible]			
12	Rapid to σ = C	Pulse Ldg	[illegible]	0.006	3[illegible]					0.1[illegible]	0.[illegible]	[illegible]60	[illegible]15			
13	Rapid to σ = C	Pulse Ldg	2.1	0.006	45.0					0.[illegible]	0.73	70	85			
15	Slow σ ≠ C	Pulse Ldg	[illegible]	[illegible]	[illegible]					0.11	0.55					
NSL 16	Rapid to σ = C	Pulse Ldg	4.[illegible]	0.006	[illegible]					0.34	1.05	170	275			

*Basic value used in stress parameter

**Time over static upper yield stress, σ_{uy}

***Extensometer point marks on gage section

TABLE 51 SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen***	Type of Loading	Testing Machine Used	Temp., °F	"Rise time" of load, sec.	Nominal Stress, ksi σ_{uy}	σ_{ly}	σ_{max}	Reduction of Area, %	Elongation in 1 in. gage, %	$\frac{\sigma_{uy} - \sigma_{uy}}{\sigma_{uy}}$	$\frac{\sigma_{uy} - \sigma_{uy}}{\sigma_{uy}}$	Delay time to SR-[illegible] strain yield, milliseconds	Delay time [illegible] psi, milliseconds	[illegible]	[illegible]	Rate of yield [illegible]
NR 2	Slow Comp.	Baldwin	[illegible]	[illegible]	[illegible]	[illegible]				0.00						
7	Slow Comp.	Pulse Lig	[illegible]	[illegible]	51..					[illegible]	0.[illegible]					
[illegible]	Rapid Comp.	Pulse Lig	[illegible]	0.005	[illegible]					[illegible]	0.1		[illegible]			
[illegible]	Rapid Comp.	Pulse Lig	[illegible].1	0.005	[illegible]					[illegible]	[illegible]		[illegible]			
[illegible]	Rapid Comp.	Pulse Lig	[illegible]	[illegible]	[illegible]					[illegible].1	[illegible]		51			
7	Slow Tension	Baldwin	[illegible]	[illegible]	[illegible]	[illegible]	71.[illegible]	[illegible]	[illegible]5	[illegible]						
[illegible]	Slow Tension	Pulse Lig	[illegible]	[illegible]	[illegible]					[illegible]						
[illegible]	Rapid Tension	Pulse Lig	1.[illegible]	0.005	[illegible]					[illegible]	[illegible]		[illegible]			
10	Rapid Tension	Pulse Lig	[illegible]	0.005	[illegible]					0.1[illegible]	0.10		[illegible]			
11	Rapid Tension	Pulse Lig	[illegible]	0.005	[illegible]					[illegible]	[illegible]		1[illegible]			
NR[illegible]	Rapid Tension	Pulse Lig	1.[illegible]	[illegible].005	[illegible]					0.2[illegible]	[illegible]		[illegible]			

*Basic value used in stress parameter

**Time over static upper yield stress, σ_{uy}

***Extensometer point marks on gage section

TABLE 5J SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Loading, %**	Rise time* of load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_c - \sigma^*_{uy}}$	***Time to SR-4 Strain yield Milliseconds	**Time to σ/σ_c = Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_c - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
					σ_u	σ_{ly}	σ_{max}									
NNL 1	Slow $\dot{\epsilon} = C_2$	Baldwin		90	54.7	51.6	67.9	55	58	0.02				-0.02	-0.05	
2	Rapid to $\sigma = C_1$	Pulse Ldg	7.3	0.006	56.9					0.06	0.25	200		0.[illegible]9	0.29	
3	Rapid to $\sigma = C_1$	Pulse Ldg	8.5	0.006	60.5					0.15	0.49	12		0.16	0.55	
4	Rapid to $\sigma = C_1$	Pulse Ldg	3.3	0.006	65.1					0.17	0.67	12		0.[illegible]	0.69	
5	Rapid to $\sigma = C_1$	Pulse Ldg	4.5	0.006	68.8					0.26	1.07	5		0.31	1.06	
6	Slow $\dot{\epsilon} = C_2$	Baldwin		90	55.7	52.4	67.8	55	38	0.00	0.00			0.00	0.00	
7	Rapid to $\sigma = C$	Pulse Ldg	0.8	0.006	57.9					0.08	0.30	150		0.10	0.36	
8	Rapid to $\sigma = C$	Pulse Ldg	2.8	0.006	59.0					0.10	0.38	35		0.13	0.45	
9	Rapid to $\sigma = C$	Pulse Ldg	3.9	0.006	67.4					0.26	0.97	25		0.29	0.97	
10	Rapid to $\sigma = C$	Pulse Ldg	0.6	0.006	74.9					0.59	1.50	5		0.43	1.46	
11 A1	20 ms. Pulse	Pulse Ldg	3.7	0.006	5[illegible].9					0.[illegible]	0.44			0.14	0.49	
11 A2	Rapid to $\sigma = C_1$	Pulse Ldg	1.8	0.006	59.0					0.10	0.38	86		0.23	0.43	
NNL 12	Slow $\dot{\epsilon} = C_2$	Baldwin		90	55.7	52.1	66.9	56	56	0.04				-0.01	-0.02	

*Basic value used in stress parameter
**Time over static upper yield stress, σ^*_{uy}
***Extensometer point marks on gage section

TABLE [illegible] SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	[illegible]	Rise time of load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy} - \sigma_H}$	Time to 5% strain yield, milliseconds	Time to $d/$ = milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
					σ_{uy}	σ_{ly}	σ_{max}									
[illegible] 1	Slow $\dot{\epsilon} = C_2$	Baldwin		90	53.1	51.2	66.9	40	34	0.00				0.00	0.00	
2	Rapid to $\sigma = C_1$	Pulse Ldg	1.4	0.006	54.8					0.05	0.12	550		0.07	0.23	
3	Rapid to $\sigma = C_1$	Pulse Ldg	2.6	0.006	59.1					0.11	0.43	5700		0.15	0.52	
4	Rapid to $\sigma = C_2$	Pulse Ldg	4.3	0.006	64.8					0.22	0.85	14		0.27	0.87	
5	Rapid to $\sigma = C_2$	Pulse Ldg	0.9	0.006	70.5					0.33	1.26	4		0.38	1.23	
6	Slow $\dot{\epsilon} = C_2$	Baldwin		90	53.5	51.3	66.8	39	34	0.01				0.00	0.01	
7	Rapid to $\sigma = C_1$	Pulse Ldg	5.2	0.006	57.9					0.09	0.35	160		0.13	0.45	
8	Rapid to $\sigma = C_1$	Pulse Ldg	6.8	0.006	59.7					0.12	0.48	165		0.17	0.54	
9	Rapid to $\sigma = C_1$	Pulse Ldg	2.5	0.006	68.1					0.29	1.11	15		0.34	1.10	
10	Rapid to $\sigma = C_1$	Pulse Ldg	4.1	0.006	69.3					0.30	1.17	2		0.35	[illegible]	
11 #1	20 ms. Pulse	Pulse Ldg	1.7	0.006	59.6					0.12	0.47			0.16	0.54	
11 #2	Rapid to $\sigma = C_1$	Pulse Ldg	4.6	0.006	59.4					0.12	0.46	6		0.16	0.52	
[illegible]12	Slow $\dot{\epsilon} = C_2$	Baldwin		90	52.9	52.4	67.5	40	32	0.00				0.02	0.08	

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 51 SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Type	[illegible]	[illegible]	Nominal stress, ksi			Reduction in Area, %	Elongation in 2 in. gage, %	[illegible]	[illegible]	***Time to start of yield, milliseconds	Time to [illegible], milliseconds	[illegible]	[illegible]	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec
					[illegible]	σ_{uy}	σ_{max}									
NLI1	Slow $\dot{\epsilon} = C_2$	Baldwin		180	61.0	56.1	79.2	65	34	0.05				0.00	0.00	
2	Slow $\dot{\epsilon} = C_2$	Baldwin		180	57.2*	56.2*	79.9*	61	34	0.00				0.00	0.00	
3	Slow $\dot{\sigma} \neq C$	Pulse Ldg		20	60.4					0.04	0.11			0.07	0.18	
4	Rapid to $\sigma = C_1$	Pulse Ldg	0.7	0.005	70.1					0.21	0.55	80		0.25	0.59	
5	Rapid to $\sigma = C_1$	Pulse Ldg	1.0	0.005	67.7					0.17	0.45	1130		0.21	0.49	
6	Rapid to $\sigma = C_1$	Pulse Ldg	[illegible]	0.005	72.0					0.24	0.64	46		0.28	0.67	
7	Rapid to $\sigma = C_1$	Pulse Ldg	1.6	0.005	70.2					0.32	0.85	0		0.36	0.84	
NLI8	Rapid to $\sigma = C_1$	Pulse Ldg	0.2	0.005	73.0					0.36	0.96	0		0.41	0.96	
NLT1	Slow $\dot{\epsilon} = C_2$	Baldwin		180	57.8	54.7	77.8	62	35	0.03				0.00	0.00	
2	Slow $\dot{\epsilon} = C_2$	Baldwin		180	56.0*	54.7*	75.0*	60	35	0.00				0.00	0.00	
3	Slow $\dot{\sigma} \neq C$	Pulse Ldg		20	58.9					0.05	0.13			0.08	0.18	
4	Rapid to $\sigma = C_1$	Pulse Ldg	0.3	0.005	61.8					0.16	0.47	108		0.18	0.43	
5	Rapid to $\sigma = C_1$	Pulse Ldg	2.6	0.005	67.2					0.20	0.51	1150		0.23	0.54	
6	Rapid to $\sigma = C_1$	Pulse Ldg	2.5	0.005	71.5					0.28	0.70	13		0.31	0.72	
7	Rapid to $\sigma = C_1$	Pulse Ldg	3.2	0.005	77.2					0.38	0.96	1		0.41	0.97	
NLT8	Rapid to $\sigma = C_1$	Pulse Ldg	3.7	0.005	77.6					0.39	0.98	0.5		0.42	0.98	

*Basic value used in stress parameter

**Time over static upper yield stress, σ_{uy}

***Extensometer point marks on gage section

TABLE 5m SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	**Rise time of load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_m - \sigma^*_{uy}}$	**Time to SR-4 Strain yield Milliseconds	**Time to σ/c = 20 Msi Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_m - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
					σ_{uy}^1	σ_{ly}	σ_{max}									
NHT1.1***	Slow $\dot{\epsilon} = C_2$	Baldwin	0.5	250	80.2*		97.0*	75	26	0.00	0.00					
2	Rapid to $\sigma = C_1$	Pulse Ldg	1.2	0.006	86.0					0.07	0.31	0	30			
3	Rapid to $\sigma = C_1$	Pulse Ldg		0.006	86.2					0.07	0.32	0	2			
4	Rapid to $\sigma = C_1$	Pulse Ldg	15.6	0.006	90.4					0.13	0.54	0	3			
5	Rapid to $\sigma = C_1$	Pulse Ldg	3.1	0.006	90.3					0.13	0.54	0	3			
6	Rapid to $\sigma = C_1$	Pulse Ldg		0.006	91.2					0.15	0.62	0	0			
7	Rapid from	Pulse Ldg	2.6	0.006	83.6					0.04	0.18	0	6			
	σ = 40 ksi to $\sigma = C_1$															
8	" "	Pulse Ldg	3.2	0.006	87.0					0.08	0.56	0	0			
9	" "	Pulse Ldg	1.1	0.006	88.6					0.10	0.45	0	3			
10	" "	Pulse Ldg	3.3	0.006	87.6					0.09	0.39	0	1			
11	" "	Pulse Ldg	4.1	0.006	91.2					0.14	0.58	0	1			
12***	Slow $\dot{\epsilon} = C_2$	Baldwin	5.3	150	80.3		96.8	75	27	0.00	0.00					
13	Rapid to $\sigma = C_1$	Pulse Ldg	14.3	0.006	83.7					0.04	0.19	0	0			
14	Rapid to $\sigma = C_1$	Pulse Ldg	4.3	0.006	84.0					0.05	0.20	0	2			
15	Rapid to $\sigma = C_1$	Pulse Ldg	0.5	0.006	88.5					0.10	0.44	0	3			
16	Rapid to $\sigma = C_1$	Pulse Ldg		0.006	90.2					0.12	0.53	0	0			
17	Rapid to $\sigma = C_1$	Pulse Ldg		0.006	92.5					0.15	0.65	0	0			

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

1 Values at $\sigma/\epsilon = 20 \times 10^6$ psi

TABLE 5n SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	**Rise time** of load, sec.	Nominal Stress, ksi σ^1_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy} - \sigma^*_{ly}}$	***Time to SR-4 Strain yield Milliseconds	***Time to σ/ϵ = 20 Msi Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{uy} - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
WHYL18	Rapid from σ = 45 ksi to $\sigma = C_1$	Pulse Ldg	15.6	0.00[illegible]	85.2					0.07	0.28	0	7			
19	" "	Pulse Ldg	2.2	0.006	85.5					0.07	0.26	0	2			
20	" "	Pulse Ldg	0.5	0.006	86.7					0.06	0.55	0	0			
21	" "	Pulse Ldg	2.8	0.00[illegible]	91.1					0.15	0.58	0	1			
22	" "	Pulse Ldg	1.7	0.00[illegible]	91.2					0.14	0.59	0	0			

*Basic value used in stress parameter
**Time over static upper yield stress, σ^*_{uy}
***Extensometer point marks on gage section
1 Values at $\sigma/\epsilon = 20 \times 10^6$ psi

TABLE 50 SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of loading	Testing Machine Used	$\dot{\epsilon}$ [illegible]	Rise time** of load, sec.	Nominal Stress, ksi σ_{uy}^{1}	σ_{ly}	σ_{max}	Reduction in Area, %	Elongation in 2 in. gage, %	[illegible]	[illegible]	Time to [illegible] Strain yield, milliseconds	Time to σ/ϵ = 20 Msi, milliseconds	[illegible]	[illegible]	Rate of yield at $\sigma = \sigma_{ly}$, in./in./sec.
HRHT 1***	Slow $\dot{\epsilon} - C_2$	Baldwin	5.4	180	85.2		[illegible]	68	20	0.01	0.07					
2	Rapid to $\sigma = C_1$	Pulse Ldg	[illegible]	0.006	85.4					[illegible]	0.08	150	[illegible]			
3	Rapid to $\sigma = C_1$	Pulse Ldg	1.0	0.006	[illegible]					0.05	0.14	0	15			
[illegible]	Rapid to $\sigma = C_1$	Pulse Ldg	[illegible]	0.006	86.8					[illegible]	0.29	50	126			
5	Rapid to $\sigma = C_1$	Pulse Ldg	[illegible]	0.006	86.5					[illegible]	0.27	0	2			
6	Rapid to $\sigma = C_1$	Pulse Ldg	1.8	0.006	91.0					0.06	0.43	0	0			
7	Rapid from σ = 45 ksi to $\sigma = C_1$	Pulse Ldg	0.9	0.006	85.0					0.01	[illegible]	200	[illegible]			
8	"	Pulse Ldg	9.8	0.006	[illegible]					0.05	0.27	1200	1937			
9	"	Pulse Ldg	0.2	[illegible]	[illegible]					[illegible]	[illegible]	0	[illegible]			
10	"	Pulse Ldg	[illegible]	[illegible]	93.1					0.11	[illegible]	14	17			
11	"	Pulse Ldg	0.2	[illegible]	[illegible]					0.14	[illegible]	1	7			
12***	Slow $\dot{\epsilon} - C_2$	Baldwin	5.0	150	84.1		100.3	69	25	0.00	0.00					
13	Rapid to $\sigma = C_1$	Pulse Ldg	[illegible]	0.006	[illegible]					0.03	0.17	0	70			
14	Rapid to $\sigma = C_1$	Pulse Ldg	0.3	[illegible]	[illegible]					[illegible]	[illegible]	14	[illegible]			
15	Rapid to $\sigma = C_1$	Pulse Ldg	0.1	[illegible]	[illegible]					0.05	0.29	0	2			
16	Rapid to $\sigma = C_1$	Pulse Ldg	1.2	0.006	91.3					[illegible]	0.44	0	3			
17	Rapid to $\sigma = C_1$	Pulse Ldg		0.006	90.7					0.08	0.41	0	0			

*Basic value used in stress parameter

**Time over static upper yield stress, σ_{uy}^{*}

***Extensometer point marks on gage section

1 Values at σ/ϵ = 20 x 10^6 psi

TABLE 5p SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	*Rise time of load, sec.	Nominal Stress, ksi σ_{uy}^{1}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma_m - \sigma^*_{uy}}$	**Time to SRL Strain yield Milliseconds	**Time to σ/ϵ = 20 msi Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma_m - \sigma^*_{ly}}$	Rate of yield at $\sigma = \sigma_{ly}$, in./in./sec.
MRYT18	Rapid from	Pulse Ldg	0.2	0.006	86.1					0.22	0.12	0	45			
	σ = 45 ksi to $\sigma_i = C_1$															
19	" "	Pulse Ldg	2.4	0.006	89.1					0.06	0.51	0	14			
20	" "	Pulse Ldg	4.2	0.006	91.5					0.09	0.56	0	4			
21	" "	Pulse Ldg	9.9	0.006	92.2					0.10	0.54	0	0			
22	" "	Pulse Ldg		0.006	92.4					0.10	0.51	0	0			

*Basic value used in stress parameter
**Time over static upper yield stress, σ^*_{uy}
***Extensometer point marks on gage section
1 Values at σ/ϵ = 20 x 10^6 psi

TABLE 5q SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen ***	Type of Loading	Testing Machine Used	[illegible]	*Pulse Time of Load, Sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 2 in., %	$\frac{\sigma_{uy}-\sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy}-\sigma^*_{uy}}{\sigma^*_{ly}-\sigma^*_{uy}}$	**Time to Strain Yield, Milliseconds	**Time to σ/ϵ = 20 Msi, Milliseconds	$\frac{\sigma_{ly}-\sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly}-\sigma^*_{ly}}{\sigma^*_{uy}-\sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
Group A1																
T-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin	27.5	60	37.2	35.8	60.7	63	40							
T-14M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	7.7	0.006	43.0					0.16	0.25	151	246	0.20	0.29	0.025
T-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin	8.1	60	35.4	35.2	60.4	59	35							
T-24M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	[illegible]	0.006	[illegible]					0.34	0.42	5	19	0.35	0.45	0.100
T-34M-1F	Slow $\dot{\epsilon}$ = C	Baldwin	35.6	60	35.1	34.5	61.4	62	38							
T-34M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	5.1	0.006	[illegible]					0.41	0.55	1	6	0.44	0.56	0.775
W-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin	3.4	60	41.7	[illegible]	60.8	60	37							
W-14M-2F			No Records.													
W-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin	4.0	60	42.2	40.2	59.8	54								
W-24-2F			No Records.													
B-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin	16.4	60	36.0	35.1	60.3	61	42							
B-14M-2F			No Records.													
B-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin	2.5	60	34.0	33.2	60.4	58	40							
B-24M-2F			No Records.													
B-34M-1F	Slow $\dot{\epsilon}$ = C	Baldwin	12.8	60	36.2	35.1	61.2	50	39							
B-34M-2F			No Records.													

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5F SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen ***	Type of Loading	Testing Machine Used	Pendling, ?	*Rise time of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy}-\sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy}-\sigma^*_{uy}}{\sigma^*_{uy}-\sigma^*_{ly}}$	**Time to SR-4 Strain yield Milliseconds	**Time to σ/c =20 ksi Milliseconds	$\frac{\sigma_{ly}-\sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly}-\sigma^*_{ly}}{\sigma^*_{uy}-\sigma^*_{ly}}$	Rate of Yield at $\sigma-\sigma_{ly}$, in./in./sec
Group A?																
T-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			38.4	37.4	60.7	63	36							
T-14M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	7.0	0.006	44.0					0.14	0.25	138	165	0.18	0.28	0.087
T-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			35.2	33.0	60.8	62	39							
T-24M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	3.8	0.006	42.8					0.29	0.34	22	29	0.30	0.35	0.094
T-34M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			32.6	33.3	61.6	59	34							
T-34M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	10.?	0.006	47.3					0.36	0.55	6	17	0.40	0.55	0.239
M-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			41.5	40.6	60.9	66	36							
M-14M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	0.2	0.006	48.8					0.18	0.38	28	74	0.20	0.41	0.051
M-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			41.3	40.0	60.8	63	40							
M-24M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	0.0	0.006	54.5					0.32	0.69	6	14	0.34	0.70	0.225
B-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			32.0	35.0	60.7	22	34							
B-14M-2F	Rapid to $\sigma = C_1$	Pulse Ldg		0.006	49.5					0.47	0.48	9	16	0.41	0.55	0.345
B-24M-1E	Slow $\dot{\epsilon}$ = C	Baldwin			32.8	30.4	60.8	51	38							
B-24M-2F			No Records													
B-34M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			38.8	36.2	61.5	59	38							
B-34M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	7.9	0.006	54.9					0.41	0.71	5	5	0.52	0.74	1.55

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5a SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen***	Type of Loading	Testing Machine Used	Bending, %	*Rise time* of load, sec.	Nominal Stress, ksi σ_{uy}	σ_{ly}	σ_{max}	Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{u} - \sigma^*_{uy}}$	**Rise to 5% SP-L Strain yield Milliseconds	**Time to σ/c − 20 ksi Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{u} - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
Group B1																
T-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin	5.6		34.9	34.9	61.5	58	36							
T-14M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	17.5	0.006	42.7					0.22	0.29	15	60	0.22	0.29	0.075
T-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			32.4	32.4	60.1	60	38							
T-24M-2F			No Record													
T-34M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			35.3	34.5	60.8	60	35							
T-34M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	8.3	0.006	48.5					0.37	0.52	11	33	0.40	0.53	0.308
W-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			40.7	40.2	60.8	63	35							
W-14M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	12.[illegible]	0.006	5[illegible].0					0.38	0.76	2	5	0.54	0.77	1.21
W-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			43.5	43.1	62.4	59	35							
W-24M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	10.6	0.006	50.5					0.16	0.36	21	77	0.17	0.37	0.089
B-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			35.9	35.9	60.9	58	34							
B-14M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	5.8	0.006	48.6					0.35	0.51	6	11	0.35	0.51	0.507
B-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			34.2	32.9	60.0	58	38							
B-24M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	2.9	0.006	54.1					0.58	0.77	2	3	0.64	0.78	3.23
B-34M-1F	Slow $\dot{\epsilon}$ = C	Baldwin	10.7		37.8	37.4	61.0	59	35							
B-34M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	15.8	0.006	55.3					0.41	0.67	2	4	0.42	0.67	1.75

*Basic value used in stress parameter
**Time over static upper yield stress, σ^*_{uy}
***Extensometer point marks on gage section

TABLE 5t SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen***	Type of Loading	Testing Machine Used	Bending, %	**Rise Time of Load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy}^* - \sigma_{uy}}{\sigma_{uy}}$	$\frac{\sigma_{uy}^* - \sigma_{uy}}{\sigma_{uy}^* - \sigma_{ly}}$	***Time to Strain Yield, milliseconds	***Time to σ/ -20 ksi, milliseconds	$\frac{\sigma_{ly}^* - \sigma_{ly}}{\sigma_{ly}}$	$\frac{\sigma_{ly}^* - \sigma_{ly}}{\sigma_{uy}^* - \sigma_{ly}}$	Rate of Yield at $\epsilon = \epsilon_{ly}$, in./in./sec.
Group B2																
T-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			54.2	54.1	60.5	61	38	0.24	0.32	36	95	0.25	0.32	0.046
T-14M-2F	Rapid to σ = C_1	Pulse Ldg	0.6	0.006	42.6											
T-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			32.0	31.8	59.8	61	38	0.32	0.37	11	35	0.33	0.37	0.089
T-24M-2F	Rapid to σ = C_1	Pulse Ldg	11.9	0.006	42.2											
T-34M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			35.7	35.3	60.2	59	36	0.36	0.53	4	12	0.38	0.54	0.453
T-34M-2F	Rapid to σ = C_1	Pulse Ldg	14.7	0.006	48.7											
W-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			41.5	38.7	60.5	63	35	0.32	0.69	2	11	0.41	0.72	0.702
W-14M-2F	Rapid to σ = C_1	Pulse Ldg	0.1	0.006	54.5											
W-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			45.5	41.7	61.1	64	34	0.14	0.34	25	62	0.17	0.40	0.155
W-24M-2F	Rapid to σ = C_1	Pulse Ldg	15.2	0.006	49.5											
R-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			35.0	34.3	60.2	60	36	0.35	0.50	5	15	0.39	0.51	0.386
R-14M-2F	Rapid to σ = C_1	Pulse Ldg	5.7	0.006	47.6											
R-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			34.2	33.2	60.0	58	40	0.58	0.76	1	2	0.62	0.77	2.52
R-24M-2F	Rapid to σ = C_1	Pulse Ldg	5.5	0.006	53.9											
R-34M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			35.6	35.2	60.9	60	49	0.48	0.68	2	4	0.50	0.69	2.09
R-34M-2F	Rapid to σ = C_1	Pulse Ldg	0.0	0.006	52.9											

*Basic value used in stress parameter
**Time over static upper yield stress, σ_{uy}
***Extensometer point marks on gage section

TABLE 5a SUMMARY OF UNIAXIAL [illegible]

Specimen	Type of loading (All 2 cycle)	Testing Machine Used	Bending, %	"Rise time" of load, sec	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 1 in. gage	[illegible]	[illegible]	[illegible] strain yield [illegible]	[illegible] 20 Ksi Milliseconds	[illegible]	[illegible]	[illegible] of yield
S.R.	Slow $\sigma = C_1$	Pulse Ldg			39.9*											
	Both Cycles															
1	Tension-Comp.		4.9		42.2											
2	Tension-Comp.		12.5		41.4											
3	Compression-Ten.		6.5		46.5											
4	Compression-Ten.		16.0		47.2											
D.R.	Rapid to $\sigma = C$	Pulse Ldg			39.9*											
	Both Cycles															
1	Tension-Comp.		3.6		44.0								690			
2	Tension-Comp.		8.5		46.0								400			
3	Compression-Ten.		1.0		44.0	Tens	****						120			
4	Compression-Ten.		3.7		49.3								150			
S.D.R.	Slow to $\sigma < \sigma^*_{uy}$	Pulse Ldg			39.9*											
	Rapid to $-\sigma = C$															
1	Tension-Comp.		3.3		43.6								1930			
2	Tension-Comp.		0.7		44.0								160			
3	Compression-Ten.		1.6		45.7								730			
4	Compression-Ten.		2.0		46.6								1180			

*Basic value used in stress parameter [illegible]
**Time over static upper yield stress, [illegible]
***[illegible]
****No yield following 48.4 ksi compression

TABLE 17 SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	*Rise time* of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 1-3/4 in. gage, %	$\frac{\sigma_m - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_m - \sigma^*_{uy}}$	***Time to 5ML Strain yield Milliseconds	**Time to $d/c = 20\times10^6$ Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_m - \sigma^*_{ly}}$	Rate of Yield at $\sigma - \sigma_{ly}$, in./in./sec.
NRL 1	Slow $\delta = \sigma_1$ Tension	Pulse Ldg	0.9	79.6		41.0	66.4*	56	25.6	0.01	0.02			0.23	0.23	0.032
2	Rapid to $\sigma = c$ Tension	Pulse Ldg	0.6	0.006		45.5				0.12	0.19		250	0.36	0.37	0.176
3	Rapid to $\sigma = c$ Tension	Pulse Ldg	3.4	0.006		51.5				0.27	0.42		17	0.54	0.55	2.43
4	Rapid to $\sigma = c$ Tension	Pulse Ldg	2.1	0.006		[illegible]				0.46	0.73		1	0.78	0.79	7.63
5	Rapid to $\sigma = c$ Compression	Pulse Ldg	7.3	0.006		42.5				0.06	0.09		545	0.27	0.28	0.045
6	Rapid to $\sigma = c$ Compression	Pulse Ldg	2.8	0.006		53.6				0.34	0.52		12	0.60	0.61	3.76
7	Rapid to $\sigma = c$ Compression	Pulse Ldg	3.2	0.006		65.0				0.62	0.95		1	0.95	0.96	11.65
8	Slow $\delta = \sigma_1$ Compression	Pulse Ldg	6.1	82.0		40.0				0.00	0.00			0.20	0.20	0.014

*Basic value used in stress parameter
**Time over static upper yield stress, σ^*_{uy}
***Extensometer point marks on gage section

TABLE — SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	**Rise time of load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 1.875 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_m - \sigma^*_{uy}}$	***Time to SL? Strain yield Milliseconds	***Time to $d/c = 20 \times 10^{-6}$ Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_m - \sigma^*_{ly}}$	Rate of Yield at $\varepsilon = \sigma_{ly}$, in./in./sec.
					σ_{uy}	σ_{ly}	σ_{max}									
[illegible] 9	Slow $\zeta = \sigma_1$ Compression	Pulse Ld.	1.7	16.6	40.4	37.6										0.0023
10	Slow $\zeta = \sigma_1$ Compression	Pulse Ld.	6.5	17.0	40.0*	35.3										0.0022
11	Slow $\zeta = \sigma_1$ Tension	[illegible]	0.9	40.0	40.6*	33.4*	66.0	56	26.9							0.0024
12	Slow $\zeta = \sigma_1$ Tension	Pulse Ld.	1.4	40.0	41.0	33.4*	66.0	57	27.2							0.0020

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE . SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	**Rise time of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 1.05 in. gage, %	$\frac{\sigma_{uy} - \sigma^{s}_{uy}}{\sigma^{s}_{uy}}$	$\frac{\sigma_{uy} - \sigma^{s}_{uy}}{\sigma^{s}_{uy} - \sigma^{s}_{m}}$	***Time to SE I Strain yield, Milliseconds	***Time to $\epsilon/c = 20 \times 10^{-6}$ Milliseconds	$\frac{\sigma_{ly} - \sigma^{s}_{ly}}{\sigma^{s}_{ly}}$	$\frac{\sigma_{ly} - \sigma^{s}_{ly}}{\sigma^{s}_{m} - \sigma^{s}_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in/in/sec.
FBL 9	Slow $\dot{\sigma} = \sigma_1$ Compression	Pulse Ld.	1.7	16.6	40.4	37.6										0.0023
10	Slow $\dot{\sigma} = \sigma_1$ Compression	Pulse Ld.	6.5	17.0	40.0*	35.3										0.0022
11	Slow $\dot{\sigma} = \sigma_1$ Tension	[illegible]	0.9	40.0	40.6*	31.4*	66.0	56	26.9							0.0024
12	Slow $\dot{\sigma} = \sigma_1$ Tension	Pulse Ld.	1.4	40.0	41.0	33.4*	66.0	57	27.2							0.0070

*Basic value used in stress parameter
**Time over static upper yield stress, σ^{s}_{uy}

***Extensometer point marks on gage section

TABLE 5t SUMMARY OF UNIAXIAL STRESS [illegible] AND RESULTS

Specimen***	Type of Loading	Testing Machine Used	Bending, %	*Rise time of load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{max} - \sigma^*_{uy}}$	**Time to Strain Yield Milliseconds	**Time to σ/-20 ksi Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{max} - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
					σ_{uy}	σ_{ly}	σ_{max}									
Group B2																
T-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			[illegible]	34.1	[illegible]	61	38							
T-14M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	0.6	0.006	42.6					0.24	0.32	36	55	0.25	0.32	0.046
T-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			32.0	31.8	59.8	61	38							
T-24M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	11.9	0.006	42.2					0.32	0.37	11	35	0.33	0.37	0.089
T-34M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			35.7	35.3	60.2	59	36							
T-34M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	4.7	0.006	48.7					0.36	0.53	4	12	0.38	0.54	0.433
M-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			41.3	38.7	60.5	63	35							
M-14M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	0.1	0.006	[illegible]					0.32	[illegible]	2	11	0.41	0.72	0.732
M-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			45.5	41.7	61.1	64	34							
M-24M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	15.2	0.006	49.5					0.14	0.34	25	62	0.17	0.40	0.135
B-14M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			35.0	34.3	60.2	60	36							
B-14M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	5.7	0.006	47.6					0.36	0.50	5	15	0.39	0.51	0.386
B-24M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			34.2	33.2	60.0	58	40							
B-24M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	5.5	0.006	53.9					0.58	0.76	1	2	0.62	0.77	2.52
B-34M-1F	Slow $\dot{\epsilon}$ = C	Baldwin			35.6	35.2	60.9	60	40							
B-34M-2F	Rapid to $\sigma = C_1$	Pulse Ldg	0.6	0.006	52.9					0.48	0.68	2	4	0.50	0.60	2.09

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5a SUMMARY OF UNIAXIAL [illegible]

Specimen	Type of Loading (All 2 cycle)	Testing Machine Used	Bending, %	**"Rise time" of load, sec	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction of Area, %	Elongation in 1 in. gage	[illegible]	$\sigma_{uy} - \sigma^*_{uy}$ [illegible]	[illegible] strain yield milliseconds	[illegible] 20 Ma, Milliseconds	[illegible]	[illegible]	Rate of yield [illegible]
S.R.	Slow σ = C_1	Pulse Ldg			39.9*											
	Both Cycles															
1	Tension-Comp.		4.9		42.2											
2	Tension-Comp.		15.5		41.4											
3	Compression-Ten.		6.5		46.5											
4	Compression-Ten.		16.0		47.2											
D.R.	Rapid to σ = C	Pulse Ldg			39.9*											
	Both Cycles															
1	Tension-Comp.		5.6		44.0								690			
2	Tension-Comp.		8.5		46.0								400			
3	Compression-Ten.		1.0		44.0	Tens	****						120			
4	Compression-Ten.		3.7		49.3								150			
S.D.R.	Slow to σ<σ*$_{uy}$	Pulse Ldg			39.9*											
	Rapid to -σ = C															
1	Tension-Comp.		3.3		43.6								1930			
2	Tension-Comp.		0.7		44.0								160			
3	Compression-Ten.		1.6		45.7								730			
4	Compression-Ten.		2.0		46.6								1180			

*Basic value used in stress parameter
**Time over static upper yield stress, σ_{uy}
***[illegible] point [illegible]
****No yield following 46.4 ksi compression

TABLE [illegible] SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	*Rise time* of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 1.875 in. gage, %	$\frac{\sigma_{uy}-\sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy}-\sigma^*_{uy}}{\sigma^*_{m}-\sigma^*_{uy}}$	***Time to 5[illegible] Strain yield Milliseconds	**Time to $d/c = 20\times10^6$ Milliseconds	$\frac{\sigma_{ly}-\sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly}-\sigma^*_{ly}}{\sigma^*_{m}-\sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
RSL 1	Slow $\delta = \sigma_1$ Tension	Pulse Ldg	0.9	99.6		41.0	66.4*	56	25.6	0.01	0.02			0.23	0.23	0.032
2	Rapid to $\sigma = c$ Tension	Pulse Ldg	0.6	0.006		45.5				0.12	0.19		250	0.36	0.37	0.176
3	Rapid to $\sigma = c$ Tension	Pulse Ldg	3.4	0.006		51.5				0.27	0.42		17	0.54	0.55	2.43
4	Rapid to $\sigma = c$ Tension	Pulse Ldg	2.1	0.006		59.5				0.46	0.73		1	0.78	0.79	7.63
5	Rapid to $\sigma = c$ Compression	Pulse Ldg	7.3	0.006		42.5				0.06	0.09		545	0.27	0.28	0.045
6	Rapid to $\sigma = c$ Compression	Pulse Ldg	2.8	0.006		53.6				0.34	0.52		12	0.60	0.61	3.76
7	Rapid to $\sigma = c$ Compression	Pulse Ldg	3.2	0.006		65.0				0.62	0.95		1	0.95	0.96	11.65
8	Slow $\delta = \sigma_1$ Compression	Pulse Ldg	6.2	82.0		40.0				0.00	0.00			0.20	0.20	0.014

*Basic value used in stress parameter
**Time over static upper yield stress, σ^*_{uy}
***Extensometer point marks on gage section

TABLE [illegible] SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	**Rise time of load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 1.875 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_m - \sigma^*_{uy}}$	**Time to St [illegible] Strain Yield Milliseconds	**Time to $\epsilon/c = 20 \times 10^{6}$ Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_m - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
					σ_{uy}	σ_{ly}	σ_{max}									
NSL 9	Slow $\dot{\epsilon} = c_1$	Pulse Ldg	1.7	16.6	40.4	32.6										0.0023
	Compression															
10	Slow $\dot{\epsilon} = c_1$	Pulse Ldg	6.5	17.0	40.0*	35.3										0.0022
	Compression															
11	Slow $\dot{\epsilon} = c_1$	Pulse Ldg	0.9	40.0	40.6*	33.4*	66.0	56	26.9							0.0024
	Tension															
12	Slow $\dot{\epsilon} = c_1$	Pulse Ldg	1.4	40.0	41.0	33.4*	66.0	57	27.2							0.0020
	Tension															

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5[illegible]. SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen***	Type of Loading	Testing Machine Used	Bending, %	"Rise time" of load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 1.875in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_m - \sigma^*_{ly}}$	**Time to SR-4 Strain yield, Milliseconds	**Time to $\sigma/c = 20 \times 10^6$, Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_m - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
					σ_{uy}	σ_{ly}	σ_{max}									
FSL 1A	Slow $\dot{\epsilon} = c_1$	Pulse Ldg	3.5	38.0	38.6*	32.6*	63.8*	59	40.5	0.00	0.00			0.00	0.00	0.0013
	Tension															
2A	Rapid to $\sigma = c$	Pulse Ldg		0.006		54.3				0.41	0.62		3	0.67	0.70	18.5
	Tension															
3A	Rapid to $\sigma = c$	Pulse Ldg	5.1	0.006		43.8				0.13	0.21		202	0.34	0.36	0.249
	Tension															
4A	Rapid to $\sigma = c$	Pulse Ldg	1.8	0.006		47.5				0.23	0.35		24	0.46	0.48	1.32
	Tension															

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE [illegible] SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	Rise time** of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 1.875 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma_c - \sigma^*_{uy}}$	***Time to SR-4 Strain yield Milliseconds	***Time to $c/c = 2000 \times 10^{-6}$ Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma_c - \sigma^*_{ly}}$	Rate of Yield at σ_{ly}, in./in./sec.
FST 1	Slow $\delta = c_1$ Tension	Pulse Ldg	1.9	59.8		41.7	65.9	48	22.4	0.05	0.07			0.23	0.25	0.055
2	Rapid to $\sigma = \sigma_1$ Tension	Pulse Ldg	3.7	0.006		42.8				0.07	0.11		368	0.27	0.29	0.375
3	Rapid to $\sigma = c$ Tension	Pulse Ldg	2.6	0.006		50.4				0.26	0.42		23	0.49	0.53	3.8
4	Rapid to $\sigma = c$ Tension	Pulse Ldg	3.7	0.006		57.8				0.45	0.71		1	0.71	0.76	19
5	Rapid to $\sigma = c$ Compression	Pulse Ldg	1.5	0.006		43.9				0.09	0.15		400	0.21	0.27	-
6	Rapid to $\sigma = c$ Compression	Pulse Ldg	0.9	0.006		54.5				0.36	0.57		14	0.51	0.63	3.75
7	Rapid to $\sigma = c$ Compression	Pulse Ldg	6.8	0.006		64.9				0.61	0.98		0	0.79	0.99	72.6
8	Slow $\delta = c_1$ Compression	Pulse Ldg	3.4	62.5		40.8				0.01	0.02			0.13	0.16	0.013

*Basic value used in stress parameter
**Time over static upper yield stress, σ^*_{uy}
*** Extensometer point marks on gage section

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TABLE 5a   SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading		Testing Machine Used	Bending, %	*Rise time of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 1.875 in. gage, % ***	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^d_{uy} - \sigma^*_{uy}}$	**Time to start of strain yield, Milliseconds	**Time to $d/\epsilon = 20\times10^6$, Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^d_{ly} - \sigma^*_{ly}}$	Rate of Yield $\dot{\epsilon} = \dot{\epsilon}_{ly}$, in./in./sec.
PST 9	Slow Compression	$\dot{\epsilon} = c_1$	Pulse Ldg	0.9	23	41.4	37.2								0.03	0.03	0.0091
10	Slow Compression	$\dot{\epsilon} = c_1$	Pulse Ldg	0.3	23	40.2*	36.2*								0	0	0.0022
11	Slow Tension	$\dot{\epsilon} = c_1$	Pulse Ldg	1.7	30	40.3	34.6	65.2*	51.1	26.1					0.02	0.03	0.0007
12	Slow Tension	$\dot{\epsilon} = c_1$	Pulse Ldg	3.1	42	39.9*	33.8*	65.5	50.4	24.5					0	0	0.0001

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5.a SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of loading	Testing Machine Used	Bending, %	**Rise time of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in ***2 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_E - \sigma^*_{uy}}$	Time to SR, Strain yield, Milliseconds	Time to $\sigma/c = 20x10^6$, Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_E - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
K 1	Slow $\dot{\epsilon} = c_1$ Tension	Pulse Ldg		17.5	40.8*	36.4	65.0	67.0	30.7					0.01	0.01	0.0023
2	Rapid $\dot{\sigma} = c$ Tension	Pulse Ldg		0.006		60.7				0.49	0.76		2	0.69	0.80	13.6
4	Rapid $\dot{\sigma} = c$ Tension	Pulse Ldg		0.006		54.1				0.33	0.51		5	0.50	0.58	7.9
5	Rapid $\dot{\sigma} = c$ Tension	Pulse Ldg		0.006		47.8				0.17	0.27		15	0.33	0.38	3.0
7	Rapid $\dot{\sigma} = c$ Tension	Pulse Ldg		0.006		43.9				0.08	0.12		190	0.22	0.25	0.50
8	Slow $\dot{\epsilon} = c_1$ Tension	Pulse Ldg		18.4	37.6	36.0*	67.0*	65.5	29.3					0	0	0.0015

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5bb SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen ***	Type of loading	Testing Machine Used	Bending, %	*Rise time of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 1.5? in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_m - \sigma^*_{uy}}$	**Time to SR-L Strain yield Milliseconds	**Time to $\epsilon/c = 20 \times 10^{6}$, Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_m - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
K 17A	Slow $\dot{\epsilon} = c_1$ Tension	Pulse Ldg		18.8	38.2	36.1*	64.9	66.5	40.3							0.0010
18A	Rapid $\sigma = c$ Tension	Pulse Ldg		0.006		49.4				0.26	0.36		6	0.37	0.42	4.8
19A	Rapid $\sigma = c$ Tension	Pulse Ldg		0.006		44.3				0.13	0.18		22	0.17	0.26	0.52
20A	Slow $\dot{\epsilon} = c_1$ Tension	Pulse Ldg		15.6	39.1*	38.2	67.6*	64.5	39.2					0.06	0.07	0.0013
21A	Rapid $\sigma = c$ Tension	Pulse Ldg		0.006		40.0				0.02	0.03		144	0.11	0.12	0.066
23A	Rapid $\sigma = c$ Tension	Pulse Ldg		0.006		56.0				0.43	0.59		3	0.55	0.63	11.0

*basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5c SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	*Rise time* of load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 0.875 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{max} - \sigma^*_{uy}}$	***Time to Strain Yield, Milliseconds	**Time to $\sigma/\epsilon = 20 \times 10^6$, Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{uy} - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
					σ_{uy}	σ_{ly}	σ_{max}									
K 9	Slow $\dot{\epsilon} = c_1$ Compression	Pulse Ldg		56.8	40.3*	35.8*	67.0*			0	0			0	0	0.0014
10	Rapid $\sigma = c$ Compression	Pulse Ldg		0.006		42.0				0.04	0.06		440	0.17	0.20	0.215
11	Rapid $\sigma = c$ Compression	Pulse Ldg		0.006		45.3				0.12	0.19		72	0.26	0.30	0.425
13	Rapid $\sigma = c$ Compression	Pulse Ldg		0.006		48.5				0.20	0.31		14	0.35	0.41	1.52
15	Rapid $\sigma = c$ Compression	Pulse Ldg		0.006		53.3				0.32	0.49		5	0.49	0.56	6.3
16	Slow $\dot{\epsilon} = c_1$	Pulse Ldg		49.0	41.9	36.8								0.03	0.03	0.0028

*Basic value used in stress parameter
**Time over static upper yield stress, σ^*_{uy}
***Extensometer point marks on gage section

TABLE 5dd SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	*Rise time of load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 1.875 in. gage, %	$\frac{\sigma_{uy}-\sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy}-\sigma^*_{uy}}{\sigma^*_{uy}-\sigma^*_{t}}$	***Time to SR / Strain yield, Milliseconds	**Time to ε/c =20x10[6], Milliseconds	$\frac{\sigma_{ly}-\sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly}-\sigma^*_{ly}}{\sigma^*_{ly}-\sigma^*_{t}}$	Rate of Yield at $\sigma=\sigma_{ly}$, in./in./sec.
					σ_{uy}	σ_{ly}	σ_{max}									
Q 1	Slow Tension $\dot{\epsilon} = c_1$	Pulse Ldg	3.3	29.6	52.1*	50.2	79.6*	65.6	27.0	0	0			0	0.01	0.0018
2	Rapid Tension $\sigma = c$	Pulse Ldg		0.006		73.0				0.33	0.73		-	0.46	0.78	9.6
4	Rapid Tension $\sigma = c$	Pulse Ldg		0.006		67.0				0.29	0.54		-	0.34	0.57	7.5
5	Rapid Tension $\sigma = c$	Pulse Ldg		0.006		61.8				0.12	0.28		1	0.24	0.40	5.3
7	Rapid Tension $\sigma = c$	Pulse Ldg		0.006		54.8				0.05	0.10		76	0.10	0.16	0.72
8	Slow Tension $\dot{\epsilon} = c_1$	Pulse Ldg	1.7	30.0	55.0	50.0*	78.6							0	0	0.0016

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE 5a SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	[illegible]	**Rise time of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 1.875 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy} - \sigma^*_{ly}}$	***Time to [illegible] static yield, milliseconds	Time to $\dot{\sigma}$ = 20x10^6, milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{uy} - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
9	Slow $\dot{\epsilon} = \sigma_1$ Compression	Pulse Ldg	2.0	53.6	52.6*	50.5*	79.6*			0	0			0	0	0.0018
10	Rapid $\sigma = c$ Compression	Pulse Ldg	3.8	0.005		56.2				0.07	0.13		175	0.09	0.20	0.146
12	Rapid $\sigma = c$ Compression	Pulse Ldg	2.8	0.005		60.5				0.15	0.29		17	0.20	0.34	1.5
13	Rapid $\sigma = c$ Compression	Pulse Ldg		0.005		64.0				0.22	0.42		4	0.27	0.46	2.5
15	Rapid $\sigma = c$ Compression	Pulse Ldg		0.005		69.2				0.31	0.61		3	0.37	0.64	5.9
16	Slow $\dot{\epsilon} = \sigma_1$ Compression	Pulse Ldg	2.2	70.4	56.1	50.7								0	0.01	0.0015

*Basic value used in stress parameter
**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

TABLE [illegible] SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	*Rise time of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 1.875 in. gage, %	$\frac{\sigma_{uy} - \sigma^e_{uy}}{\sigma^e_{uy}}$	$\frac{\sigma_{uy} - \sigma^e_{uy}}{\sigma^e_{u} - \sigma^e_{uy}}$	***Time to Strain yield Milliseconds	**Time to σ/c = Milliseconds	$\frac{\sigma_{ly} - \sigma^e_{ly}}{\sigma^e_{ly}}$	$\frac{\sigma_{ly} - \sigma^e_{ly}}{\sigma^e_{u} - \sigma^e_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
	Tension	Pulse Rig														
T 1	Slow $\dot{\epsilon} = c_1$		6.5	110	113.5		130.1	89	18.9							
2	Rapid to $\sigma = c$			0.006	125.5									0.11	0.69	1.1
4	Rapid to $\sigma = c$			0.006	122.5									0.08	0.52	0.22
5	Rapid to $\sigma = c$			0.006	120.4									0.06	0.40	0.15
7	Rapid to $\sigma = c$			0.006	117.3									0.03	0.22	0.08
8	Slow $\dot{\epsilon} = c_1$		2.8	77	113.5		130.8	89	18.4							
	Compression	Pulse Rig														
T 9	Slow $\dot{\epsilon} = c_1$			69	120.0											
10	Rapid to $\sigma = c$			0.006	118.8									0.05	0.31	0.10
12	Rapid to $\sigma = c$			0.006	120.6									0.06	0.41	0.16
15	Rapid to $\sigma = c$			0.006	121.7									0.07	0.47	0.20
16	Slow $\dot{\epsilon} = c_1$			62	120.0											

*Basic value used in stress parameter
**Time over static upper yield stress, σ^e_{uy}
***Extensometer point marks on gage section

TABLE 5gg SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	*Rise time* of load, sec.	Nominal Stress, ksi σ_{uy}	Nominal Stress, ksi σ_{ly}	Nominal Stress, ksi σ_{max}	Reduction in Area, %	Elongation in 1.875 in. gage, %	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_{uy}}$	$\frac{\sigma_{uy} - \sigma^*_{uy}}{\sigma^*_m - \sigma^*_{uy}}$	***Time to SR-I Strain yield Milliseconds	**Time to $\sigma/$ = Milliseconds	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_{ly}}$	$\frac{\sigma_{ly} - \sigma^*_{ly}}{\sigma^*_m - \sigma^*_{ly}}$	Rate of Yield at $\sigma = \sigma_{ly}$, in./in./sec.
	Tension	Pulse Ldg														
L 1	Slow $\dot{\epsilon} = c_1$		1.0	49	42.5*		45.2	43	16.0							
2	Rapid to $\sigma = c$			0.006	44.7											
4	Rapid to $\sigma = c$			0.006	44.4											
5	Rapid to $\sigma = c$			0.006	43.1											
8	Slow $\dot{\epsilon} = c_1$		2.5	[illegible]	42.5*		45.4	42	15.4							
	Compression	Pulse Ldg														
L 9	Slow $\dot{\epsilon} = c_1$		4.9	81	41.0*											
10	Rapid to $\sigma = c$			0.007	41.3											
12	Rapid to $\sigma = c$			0.007	42.7											
13	Rapid to $\sigma = c$			0.007	46.1											
15	Rapid to $\sigma = c$			0.007	47.3											
16	Slow $\dot{\epsilon} = c_1$		9.9	82	41.0*											

*Basic value used in stress parameter

**Time over static upper yield stress, σ^*_{uy}

***Extensometer point marks on gage section

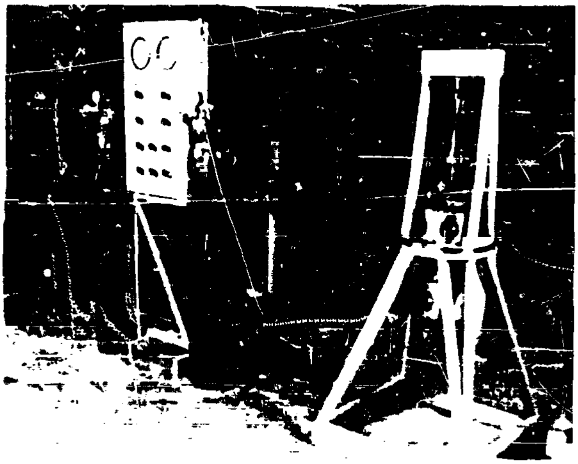


FIG. 1 PRESSURE PANEL, AND 20 KIP PULSE LOADING UNIT ARRANGED FOR TESTING UNIAXIAL TENSION SPECIMENS

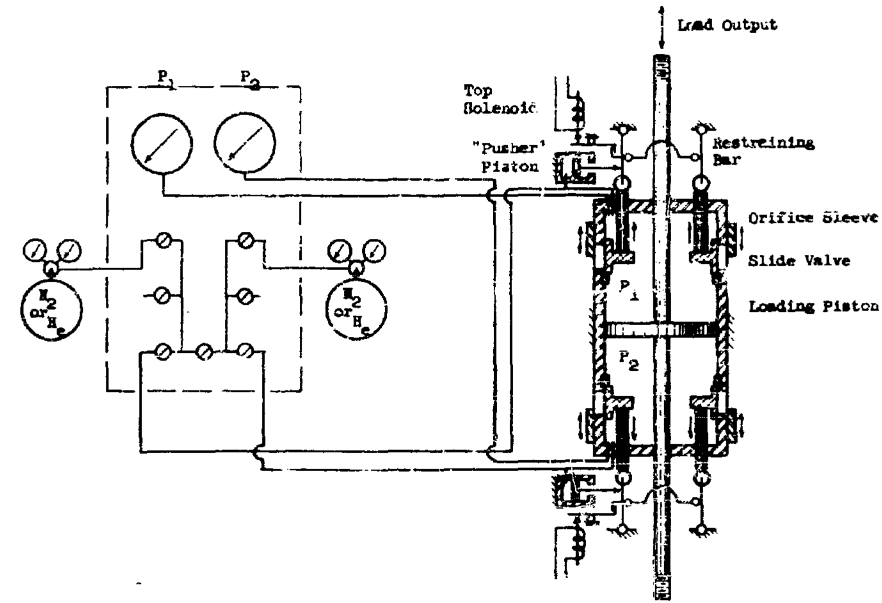


FIG. 2 SCHEMATIC REPRESENTATION OF 20 KIP PULSE LOADING APPARATUS

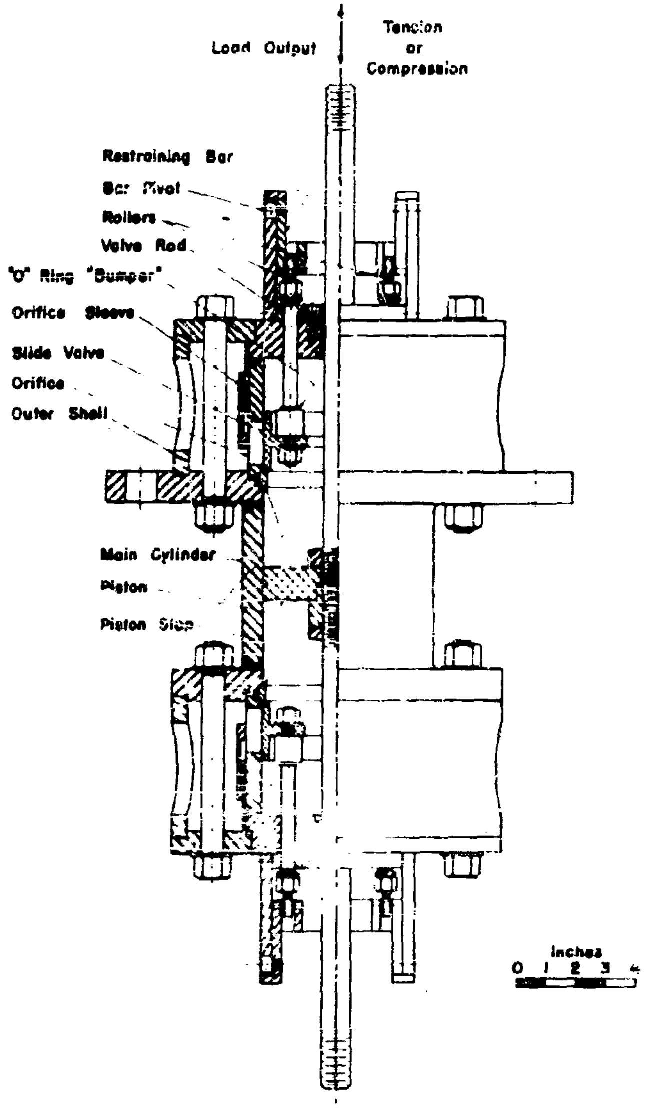


FIG. 3 20 KIP PULSE LOADING UNIT

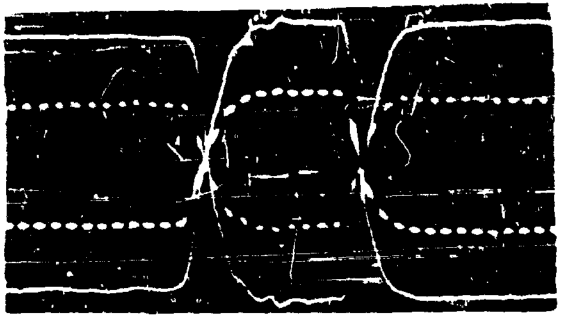


FIG. 4a 10,000 LB. PULSE - RAPID LOADING, RAPID UNLOADING - 1000 CPS TIMING

FIG. 4b 10,000 LB. PULSE - RAPID LOADING, RELATIVELY SLOW UNLOADING - 60 CPS TIMING

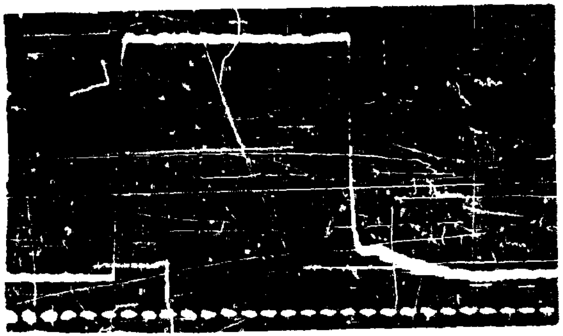


FIG. 4c 10,000 LB. PULSE - RAPID LOADING, RAPID UNLOADING - 60 CPS TIMING

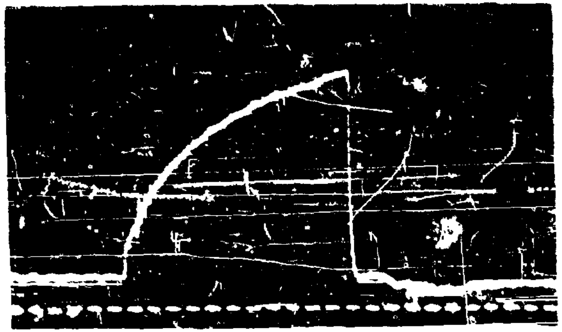


FIG. 4d 10,000 LB. PULSE - RELATIVELY SLOW LOADING, RAPID UNLOADING - 60 CPS TIMING

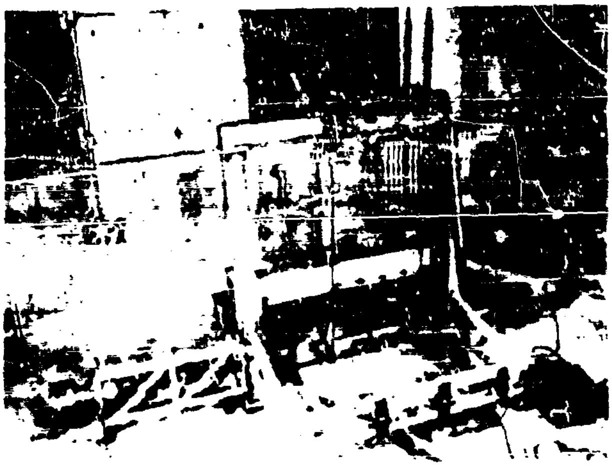


FIG. 5 PULSE LOADING UNIT BEING USED TO TEST MODEL FRAME
(Frame Shown After Testing)

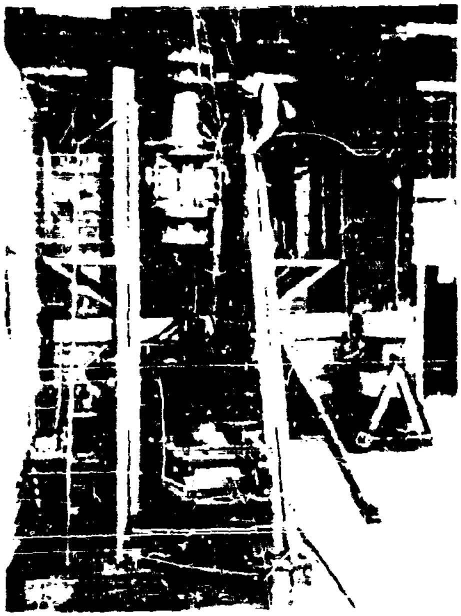


FIG. 6 60 KIP PULSE LOADING UNIT IN FRAME FOR TESTING BEAM-COLUMNS
(A 60 Kip Unit with Outer Chambers is in Background)

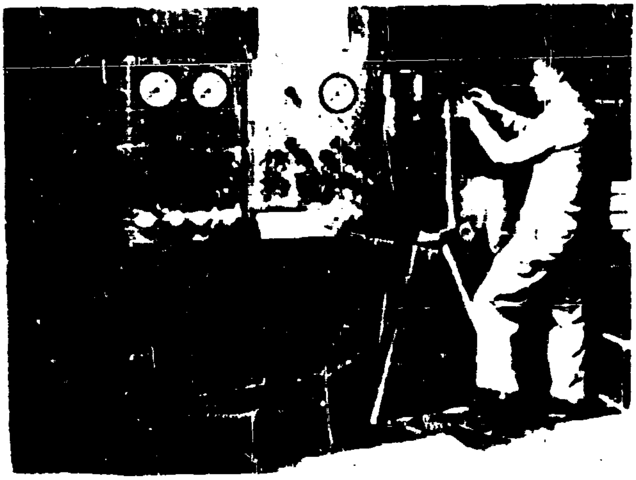


FIG. 7 20 KIP PULSE LOADING UNIT AND 20 KIP STRAINING UNIT CONNECTED IN SERIES FOR TESTING TENSION-COMPRESSION SPECIMENS; SHOWN WITH PRESSURE CONTROL PANELS

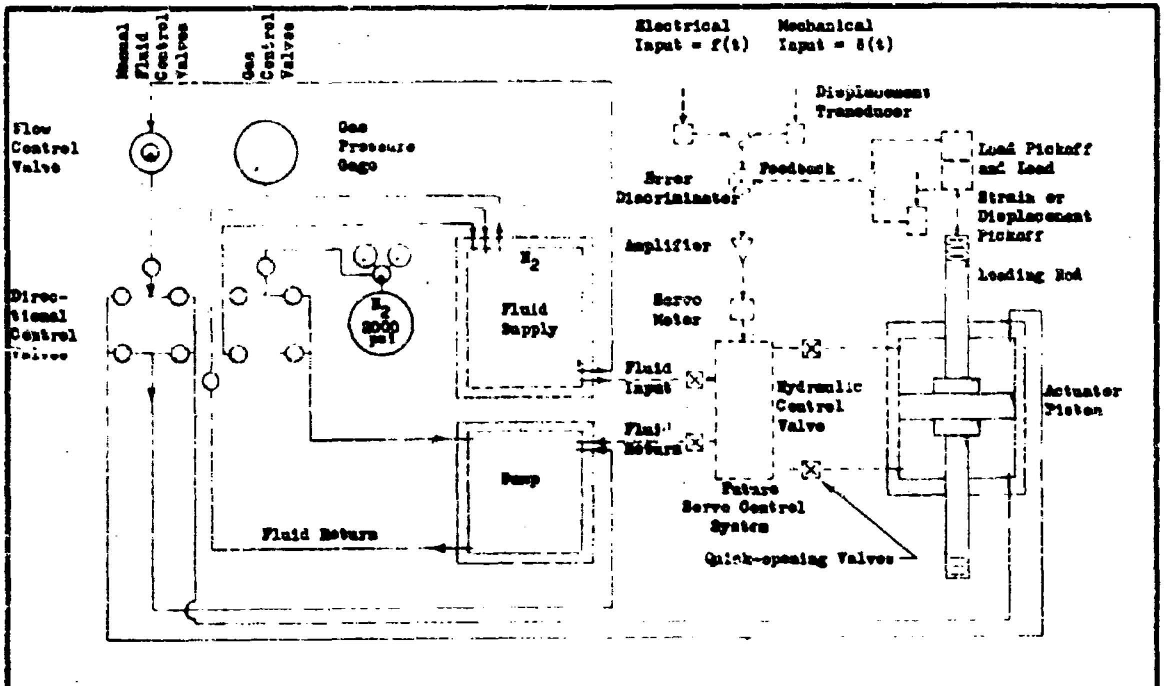


FIG. 8 SCHEMATIC REPRESENTATION OF 20 KIP STRAINING APPARATUS

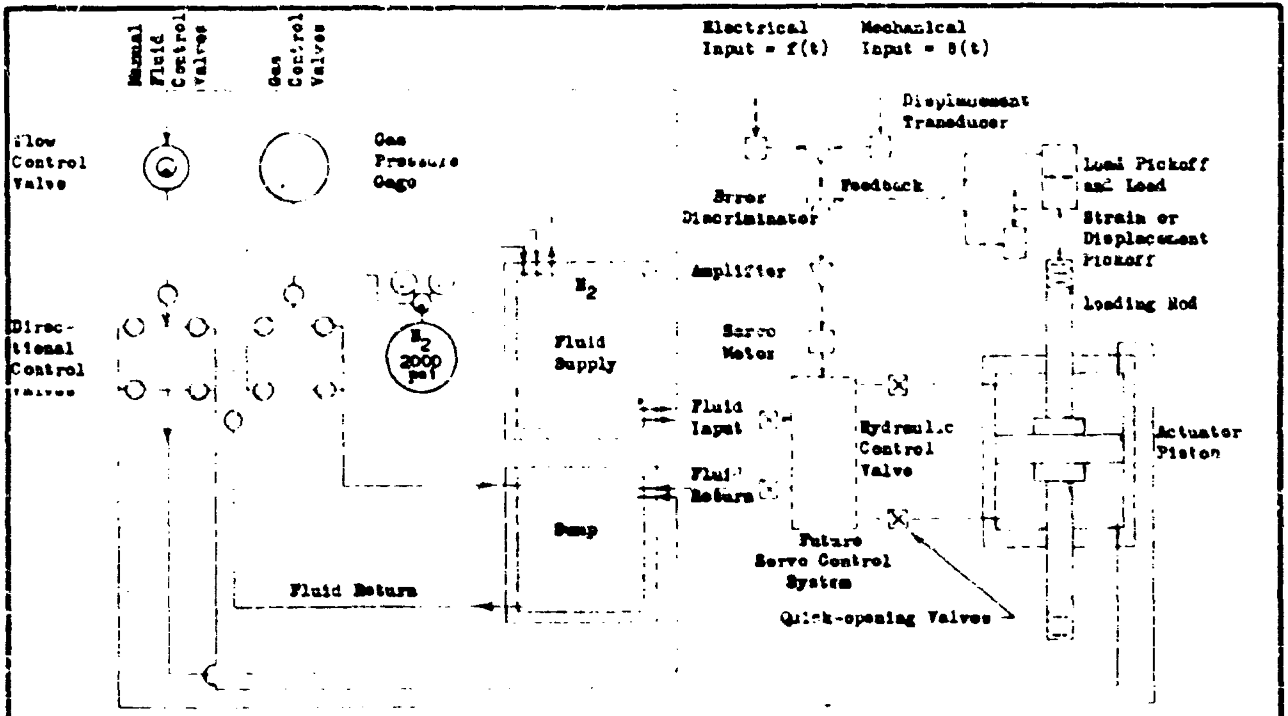


FIG. 8 SCHEMATIC REPRESENTATION OF 20 KIP STRAINING APPARATUS

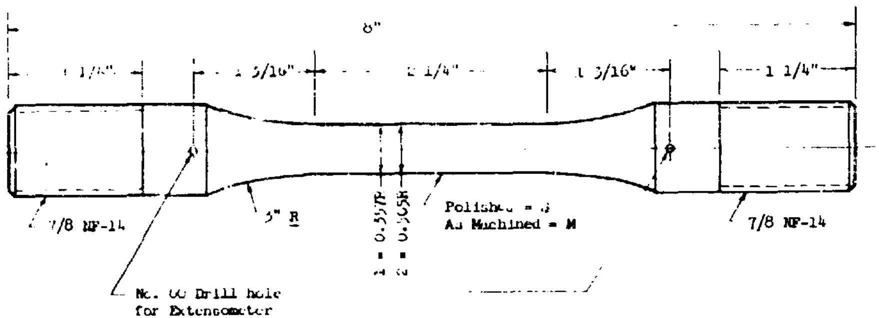


FIG. 9 DIMENSIONS OF TENSILE SPECIMENS
(Series HB, SP, NL, NST)

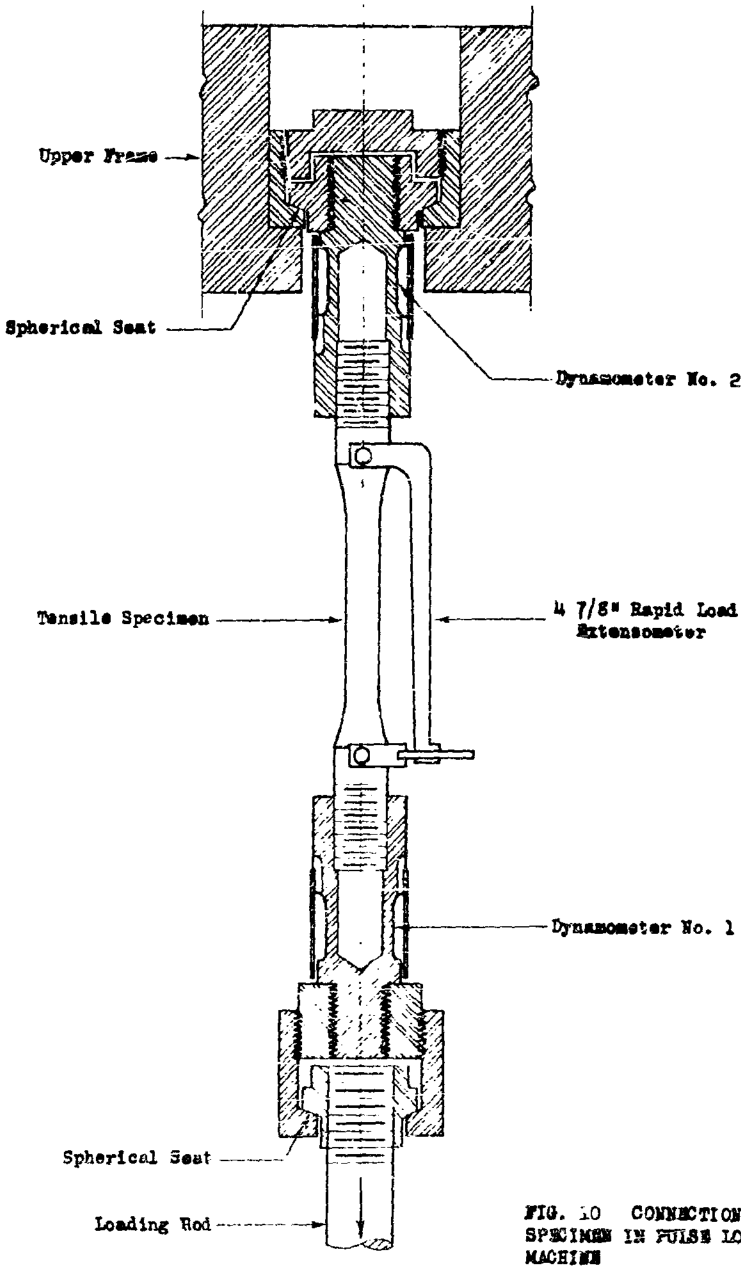


FIG. 10 CONNECTION OF TENSILE SPECIMEN IN PULSE LOADING MACHINE

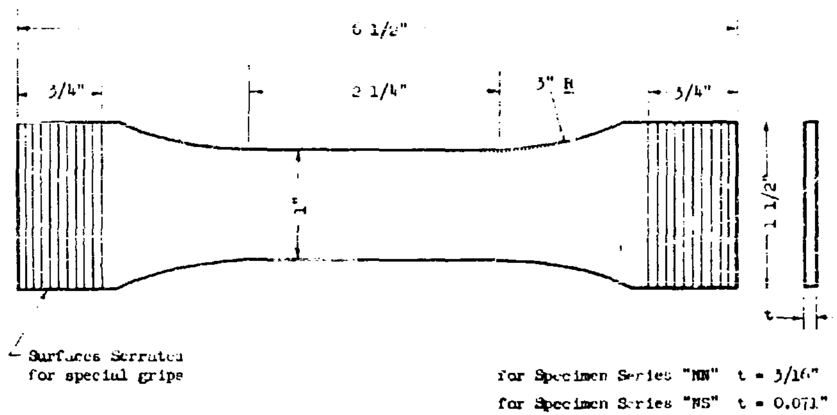
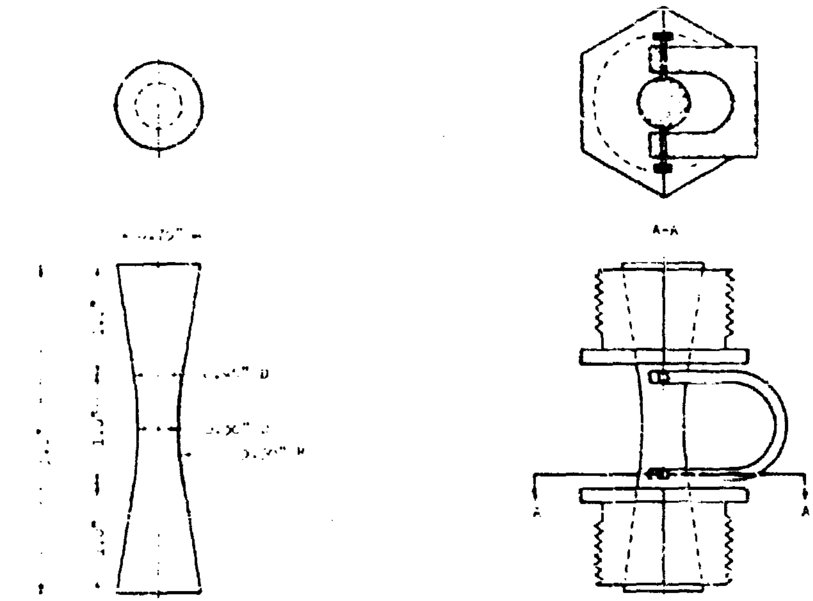


FIG. 11 DIMENSIONS OF SPECIMENS FROM SHEET STOCK
(Series NN, NS)



(a) Tension-Compression Specimen

(b) Extensometer Arrangement

FIG. 12 DIMENSIONS OF PRELIMINARY TENSION-COMPRESSION SPECIMENS
(Series MB)

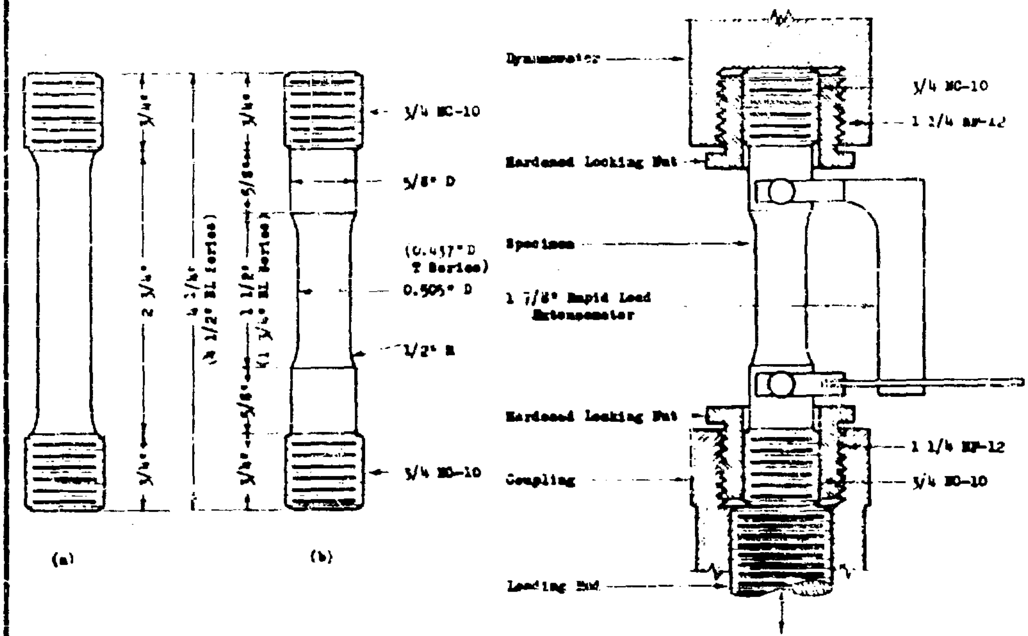


FIG. 13 DIMENSIONS OF TENSION-COMPRESSION SPECIMEN AND MANNER OF CONNECTION
(Series PSL-A, X-A; PS, X, Q, T, L)

FIG. 14a "RBA" STEEL, EDGE OF SPECIMEN 1SRBA4
(4% Picrol - 200X)

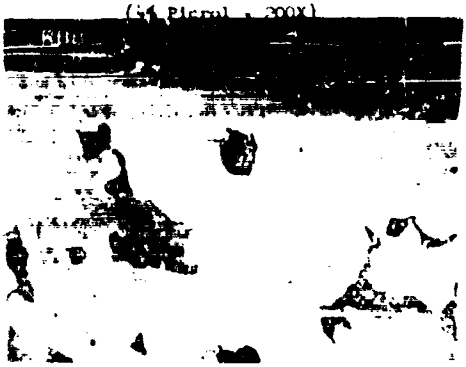


FIG. 14b "RBB" STEEL, EDGE OF SPECIMEN 1NRBB[illegible]
(4% Picrol - 200X)

FIG. 14c "RBC" STEEL, EDGE OF SPECIMEN 1SRBC4
(4% Picrol - 200X)

FIG. 14d "SPA" STEEL, EDGE OF SPECIMEN 1SPA4
(4% Picral - 200X)

FIG. 14e "SPB" STEEL, EDGE OF SPECIMEN 1NSPB
(4% Picral - 500X)

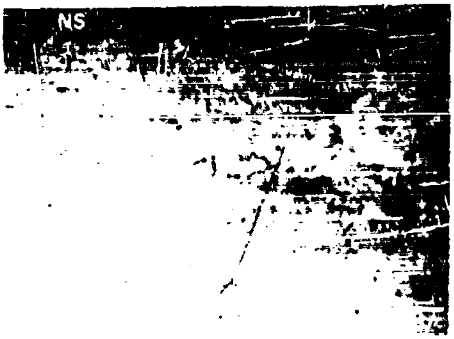


FIG. 14f "NS" STEEL, EDGE OF SPECIMEN NST4
(4% Picral - 200X)

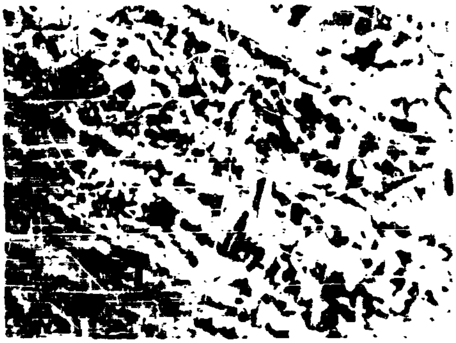


FIG. 14g "NR" STEEL, CENTER OF SPECIMEN NR2
(4% Picral - 200X)

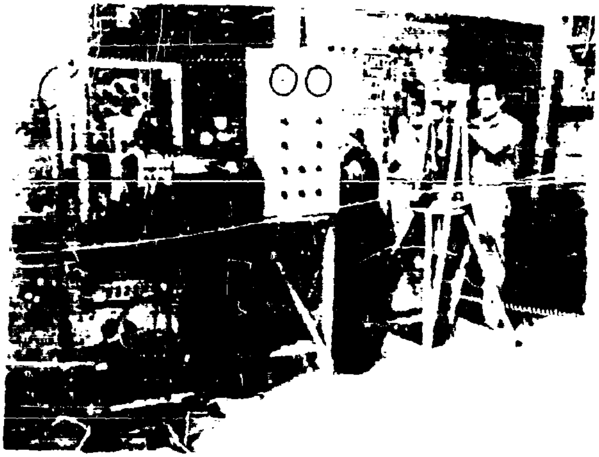


FIG. 15 CRO INSTRUMENTS, PRESSURE PANEL, AND 30 KIP PULSE LOADING UNIT ARRANGED FOR TESTING PRELIMINARY TENSION-COMPRESSION SPECIMENS

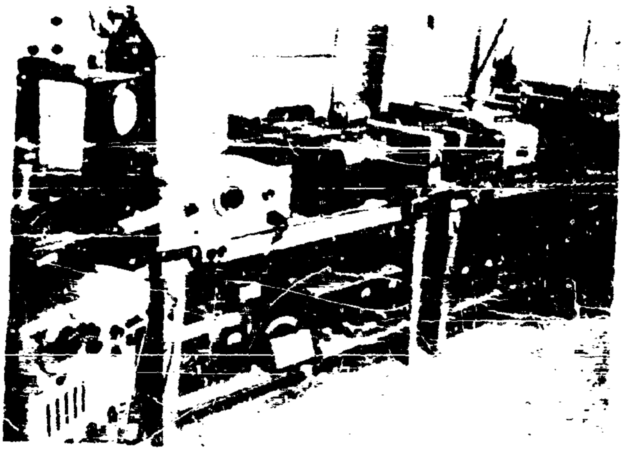


FIG. 16 HATHAWAY OSCILLOGRAPHS AND ASSOCIATED APPARATUS
(Two units used for flexure tests; one unit used for rapid uniaxial stress tests)

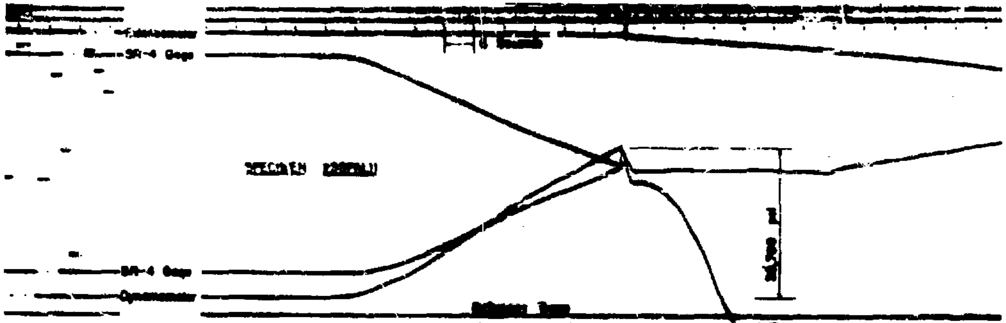


FIG. 17a OSCILLOGRAM (1/2 size) OF "SLOW" TEST IN BALDWIN MACHINE

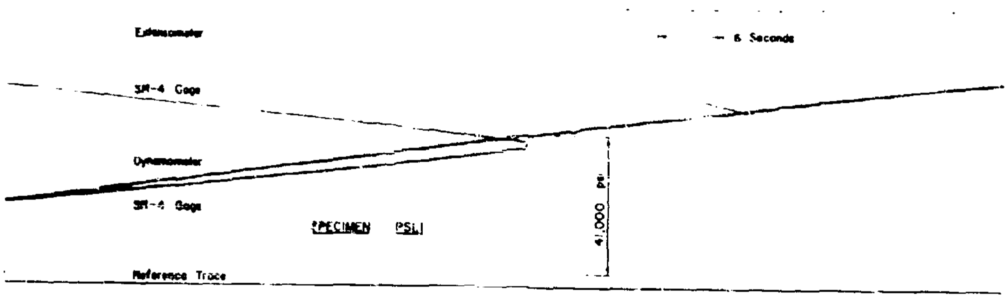


FIG. 17b OSCILLOGRAM (1/2 size) OF "SLOW" TEST IN PULSE LOADING MACHINE

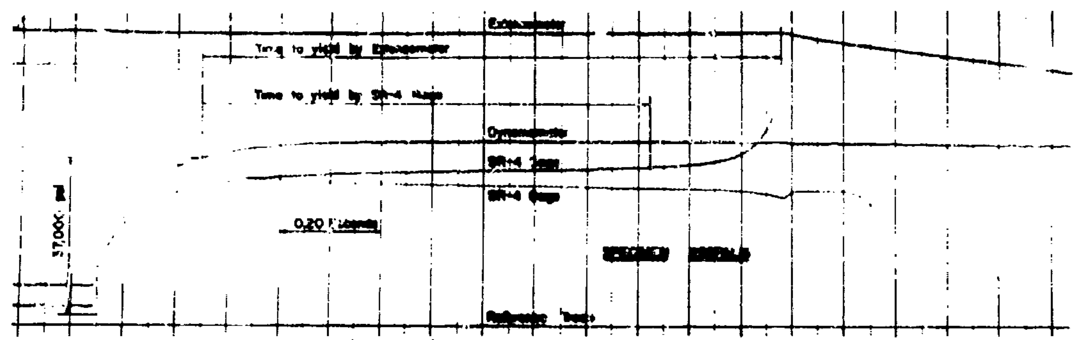


FIG. 17c OSCILLOGRAM (1/2 size) OF TEST FROM ZERO TO MAXIMUM LOAD IN ABOUT 0.5 SECONDS

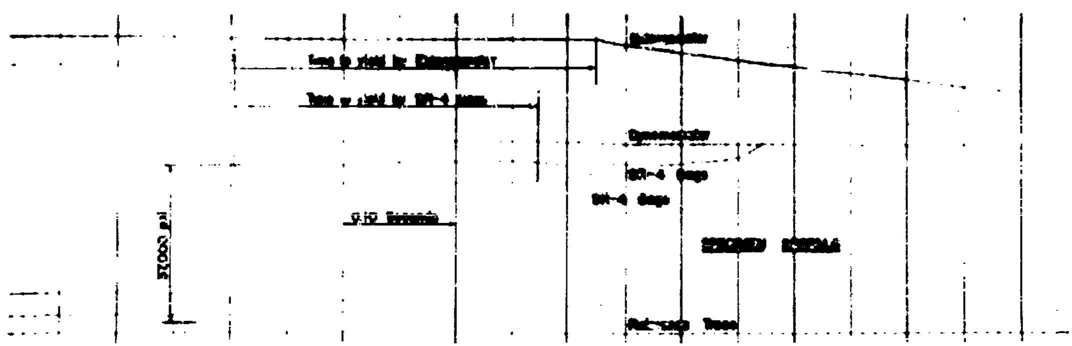


FIG. 17d OSCILLOGRAM (1/2 size) OF TEST FROM ZERO TO MAXIMUM LOAD IN ABOUT 0.10 SECONDS

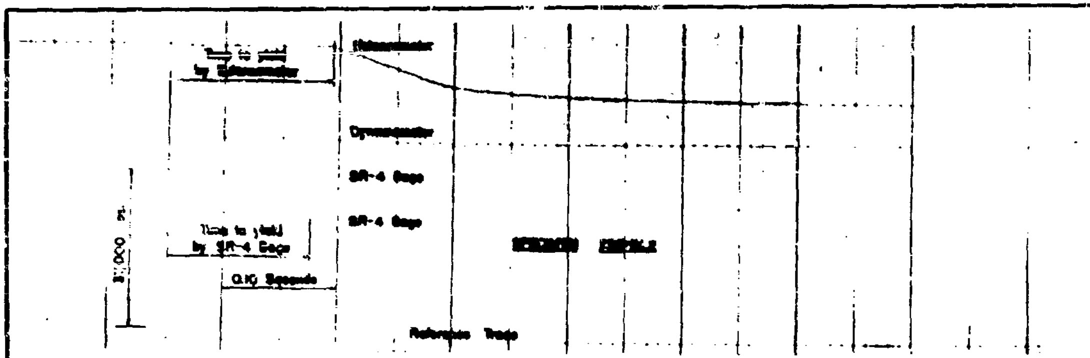


FIG. 17e OSCILLOGRAM (1/2 size) OF TEST FROM ZERO TO MAXIMUM LOAD IN ABOUT .005 SECONDS

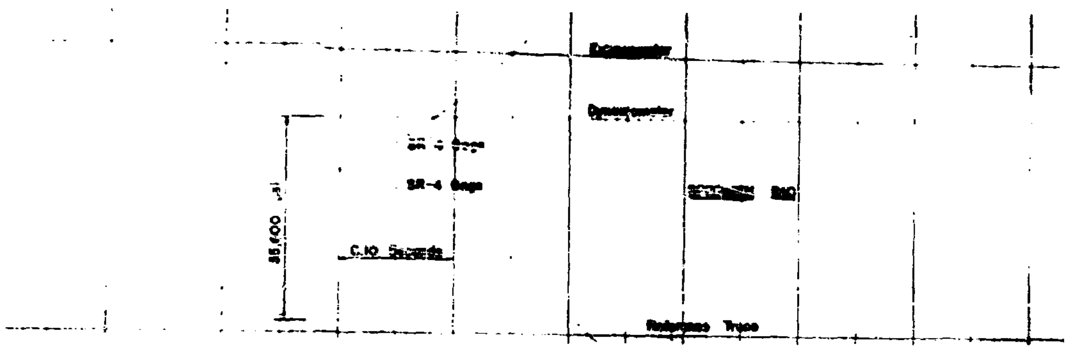


FIG. 17f OSCILLOGRAM (1/2 size) SHOWING GRADUAL YIELDING TYPICAL OF "NR" SPECIMEN SERIES

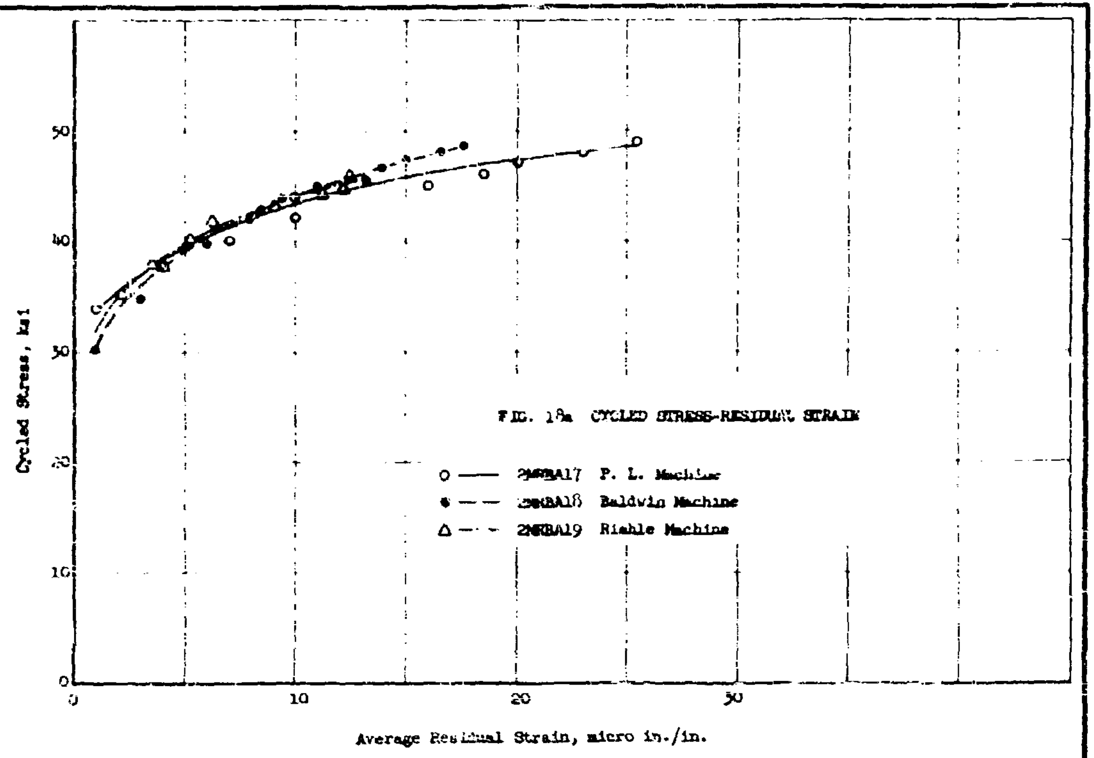


FIG. 18a CYCLED STRESS-RESIDUAL STRAIN

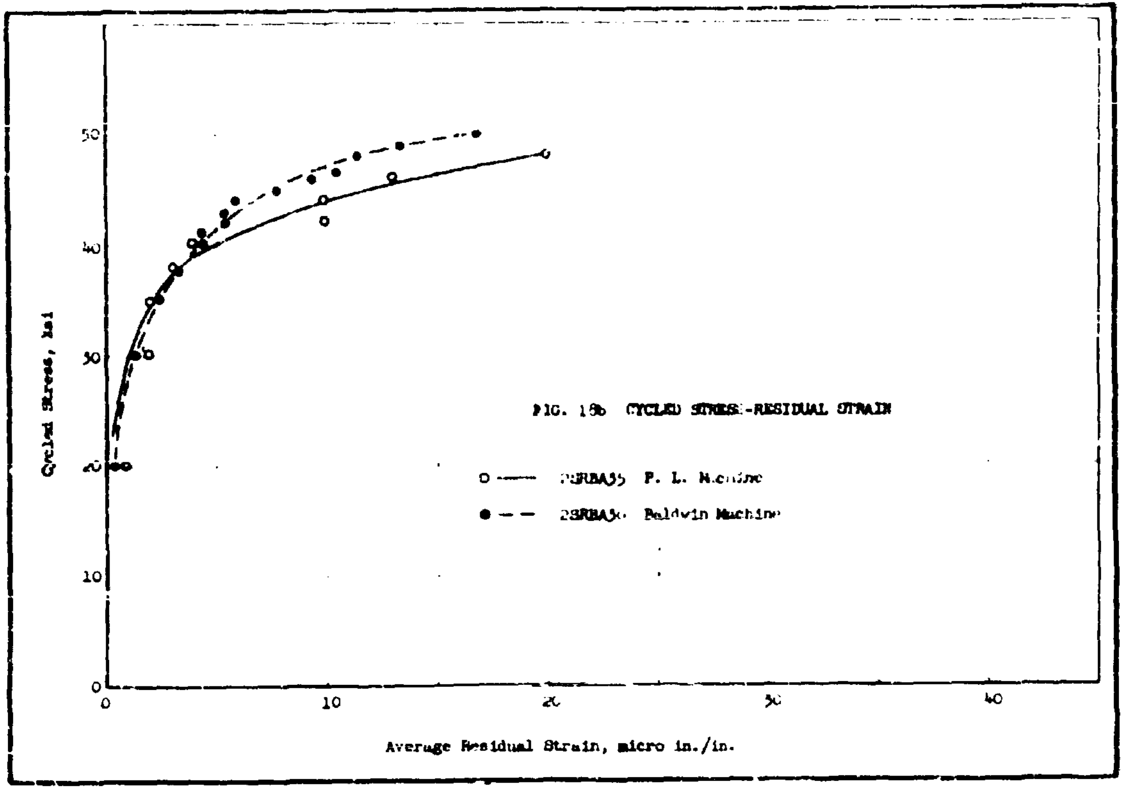


FIG. 18b CYCLED STRESS-RESIDUAL STRAIN

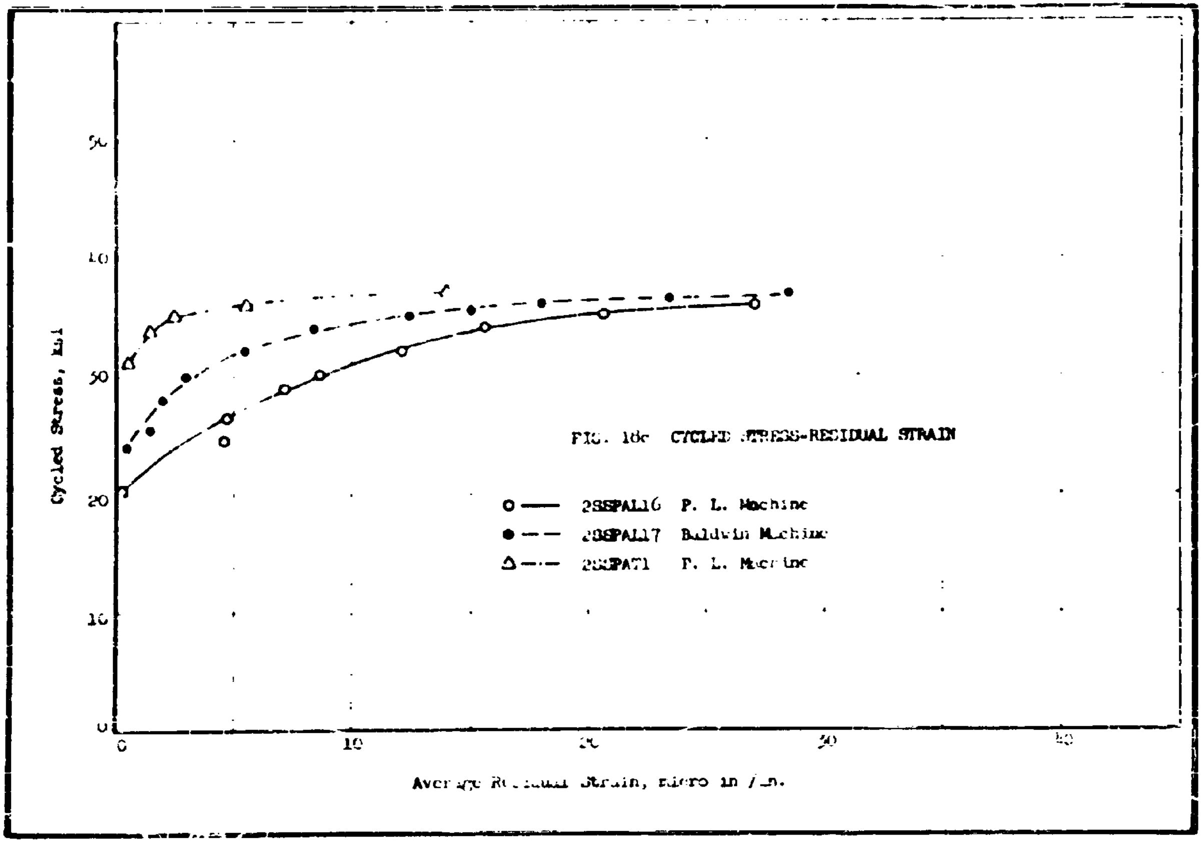


FIG. 18c CYCLED STRESS-RESIDUAL STRAIN

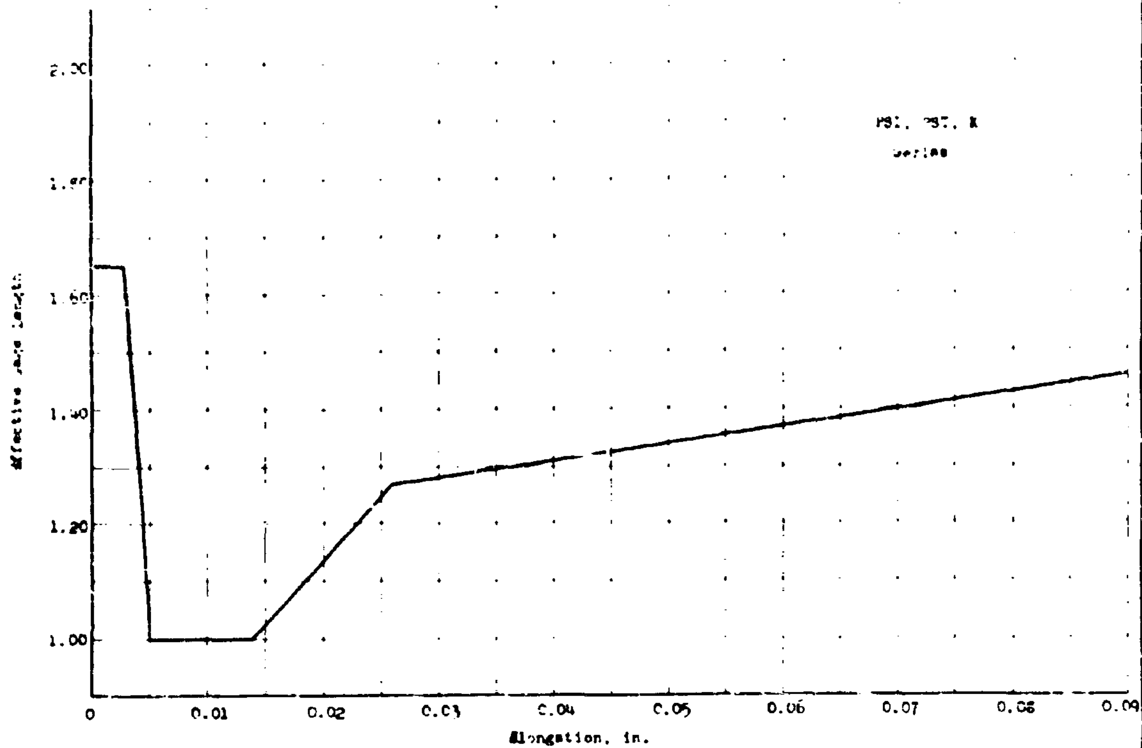


FIG. 19a EFFECTIVE GAGE LENGTH - ELONGATION

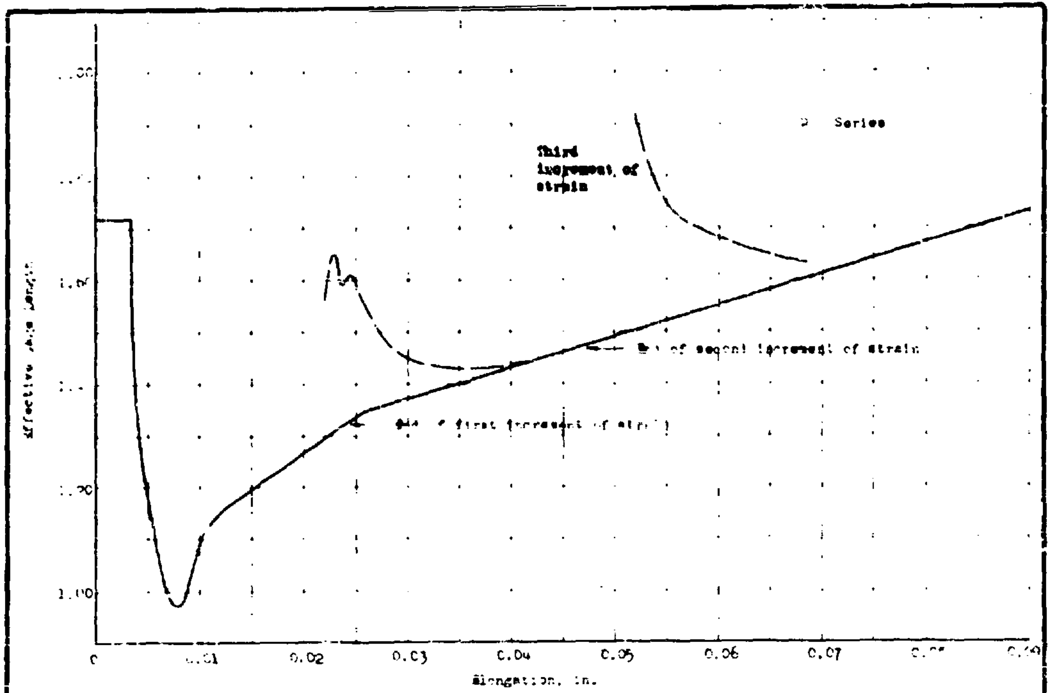


FIG. — EFFECTIVE GAGE LENGTH – ELONGATION

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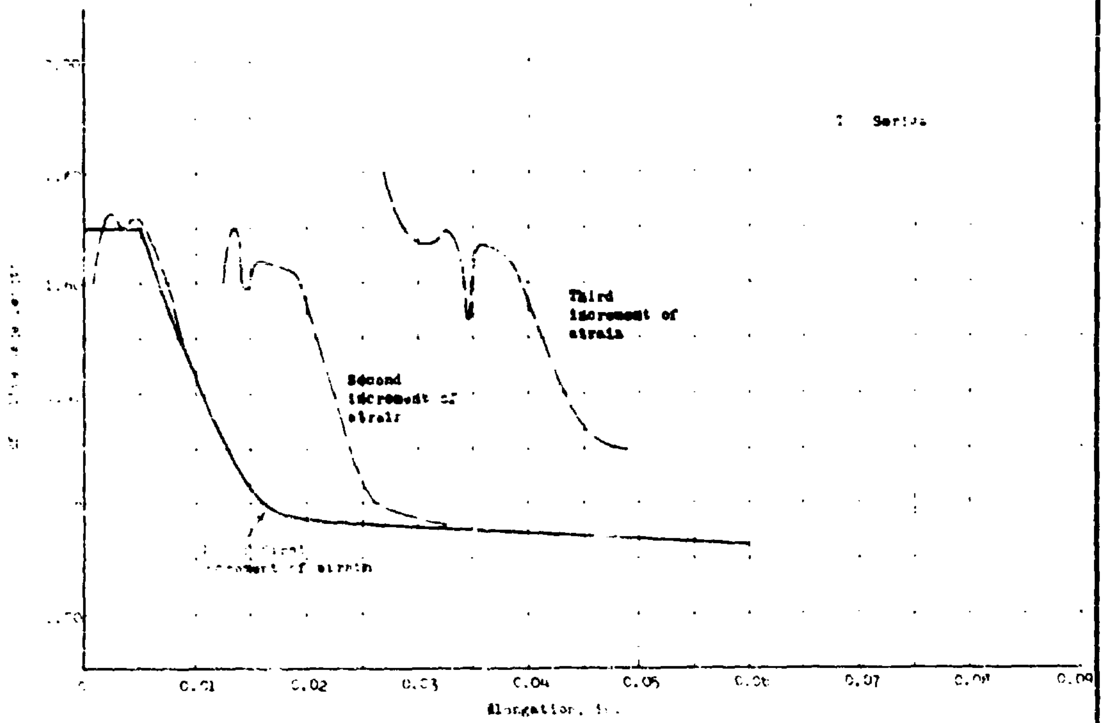


FIG. 1[illegible] EFFECTIVE GAGE LENGTH - ELONGATION

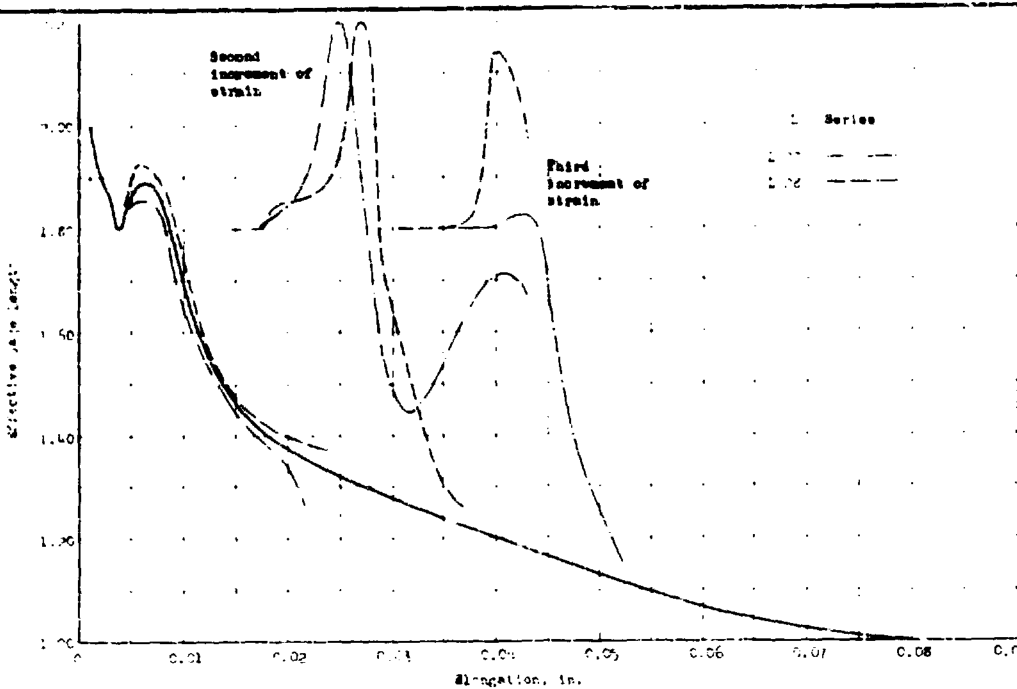


FIG. [illegible] EFFECTIVE GAGE LENGTH – ELONGATION

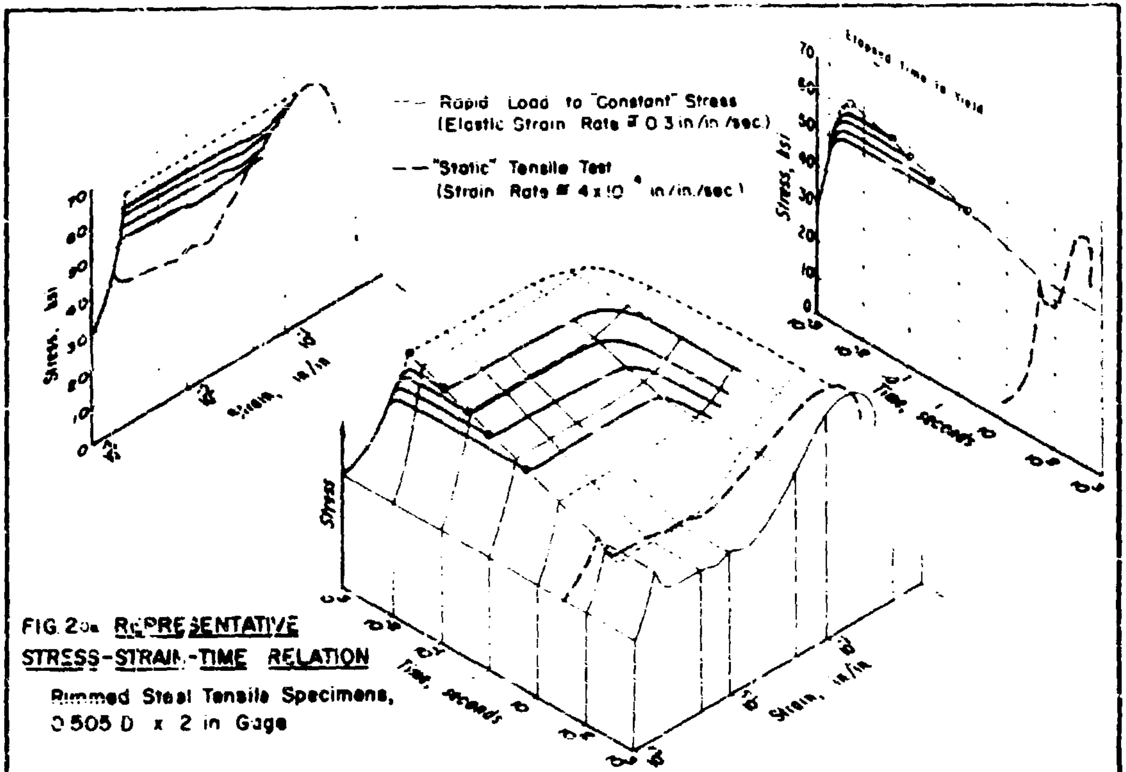


FIG. 2a REPRESENTATIVE STRESS-STRAIN-TIME RELATION

Rimmed Steel Tensile Specimens, 0.505 D x 2 in Gage

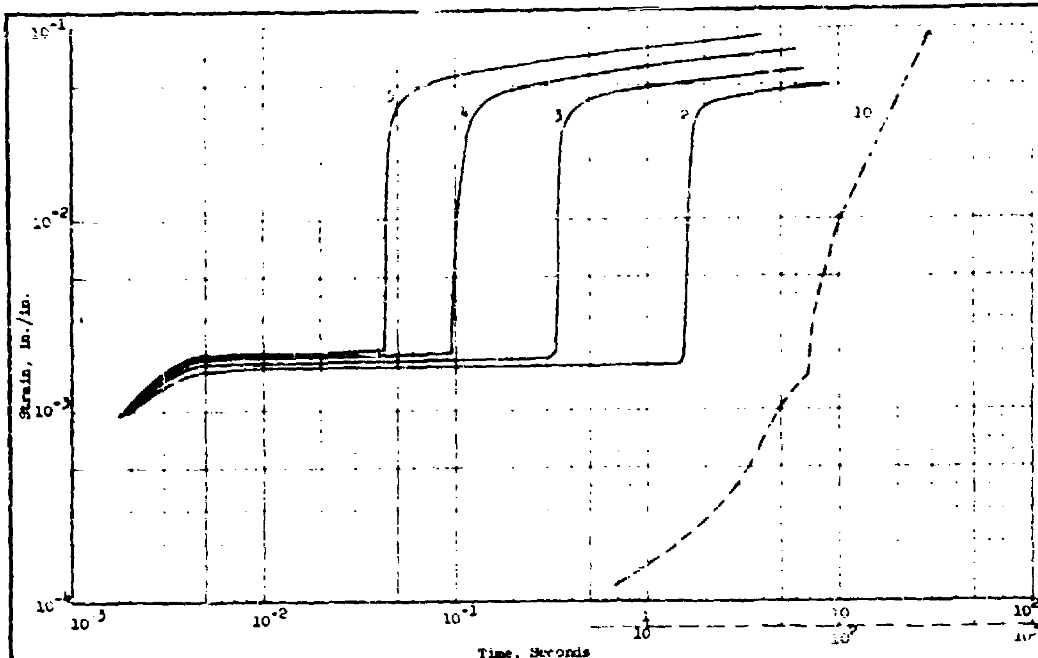


FIG. 20b STRAIN-TIME RELATION, 200BA SERIES

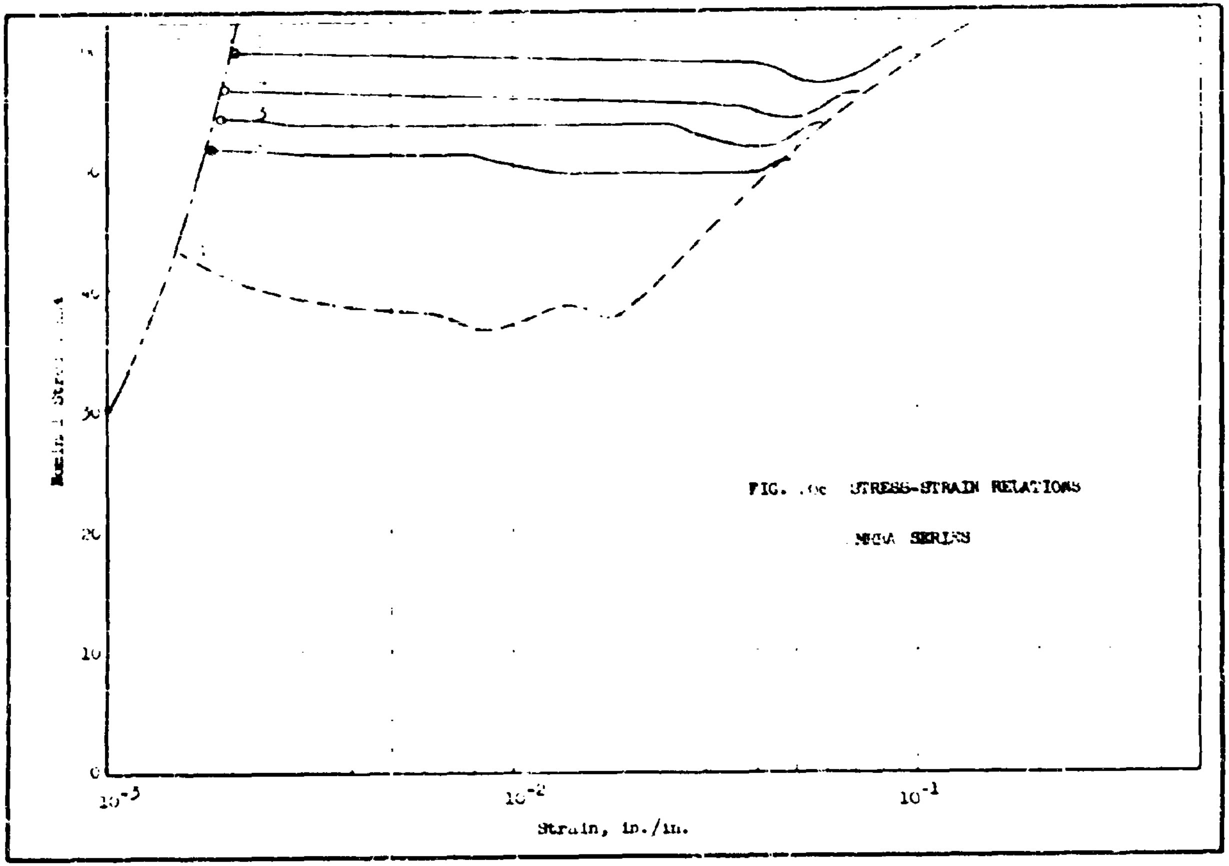


FIG. .6c STRESS-STRAIN RELATIONS

MGA SERIES

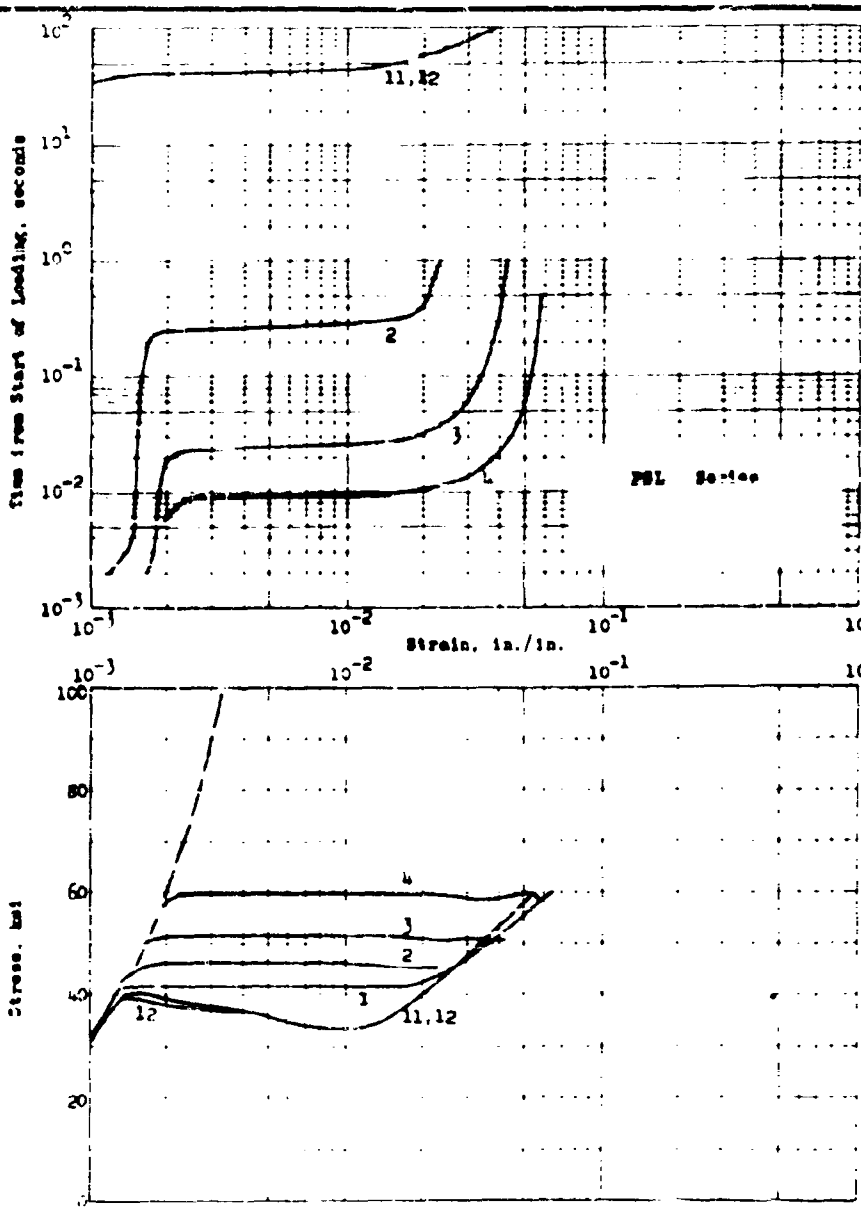


FIG. ... STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

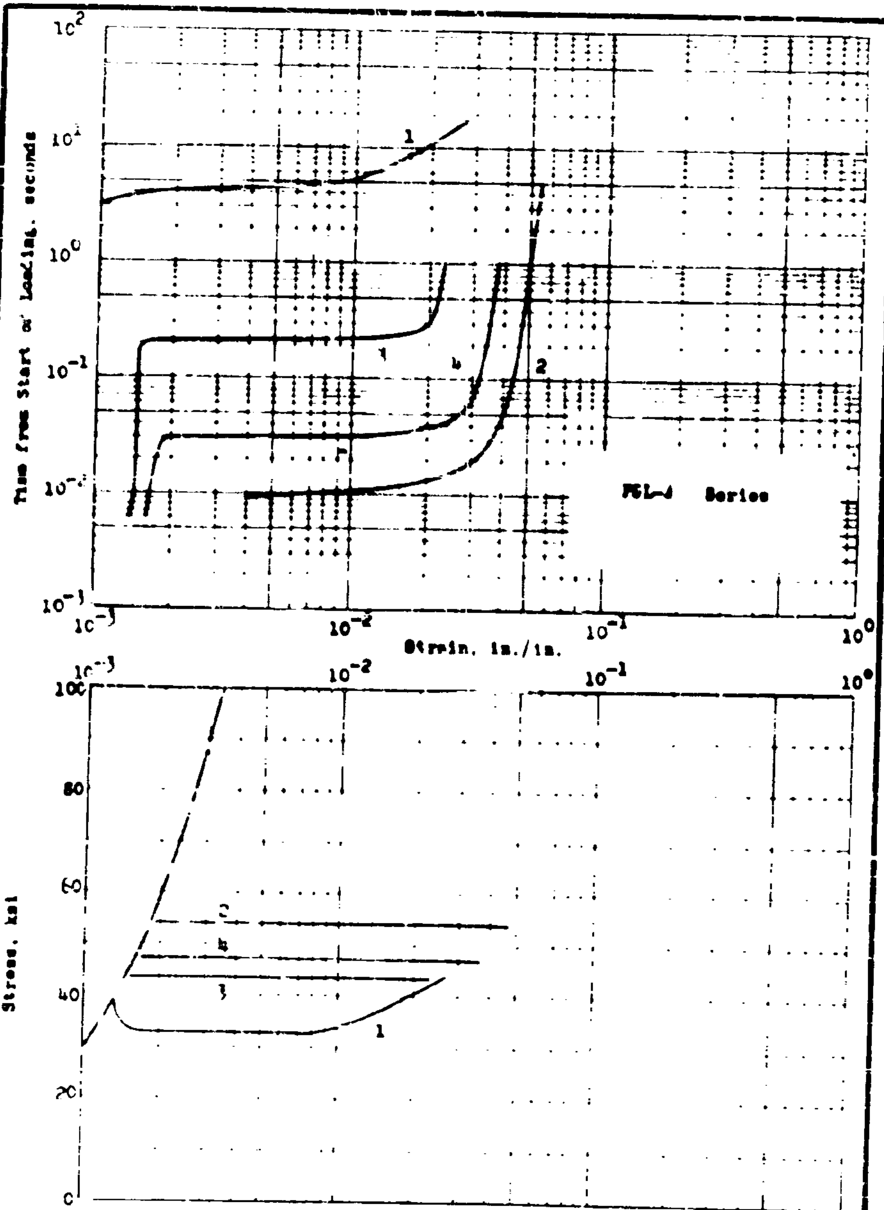


FIG. 1F STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

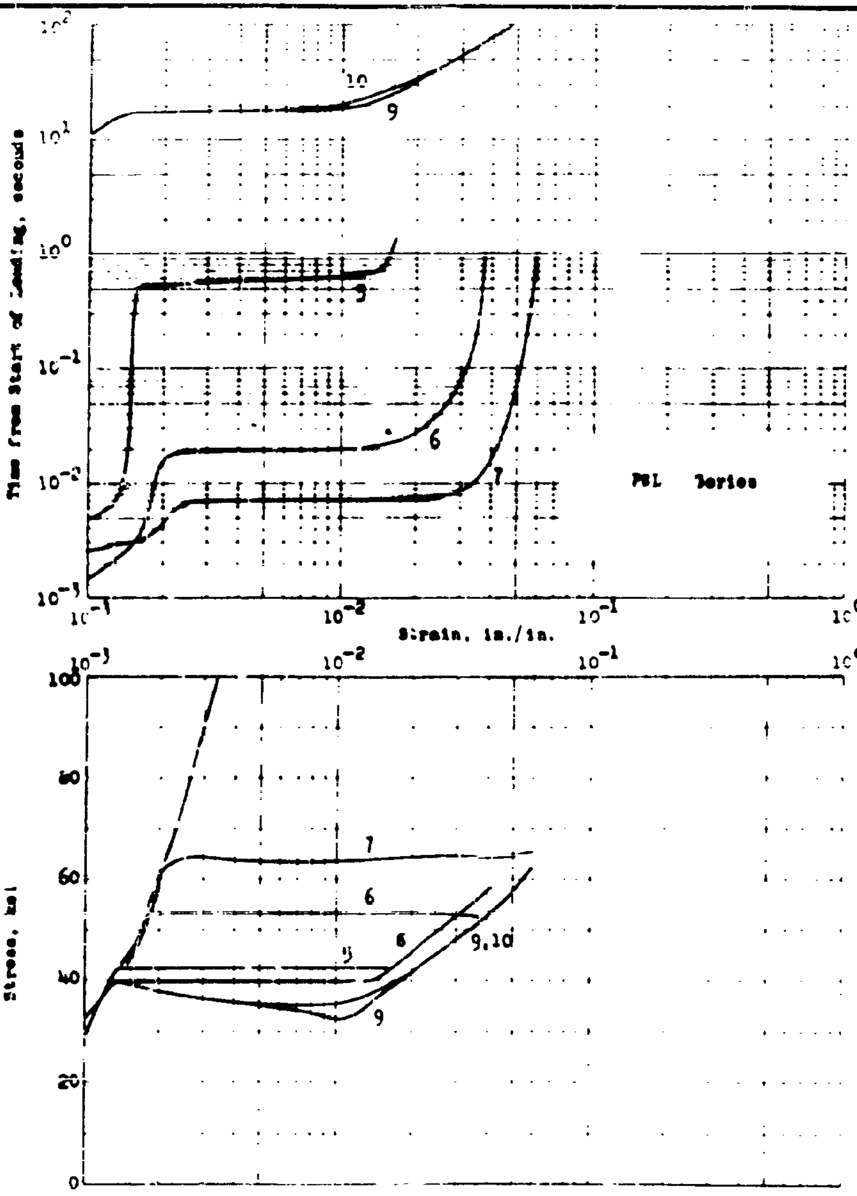


FIG.21c STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

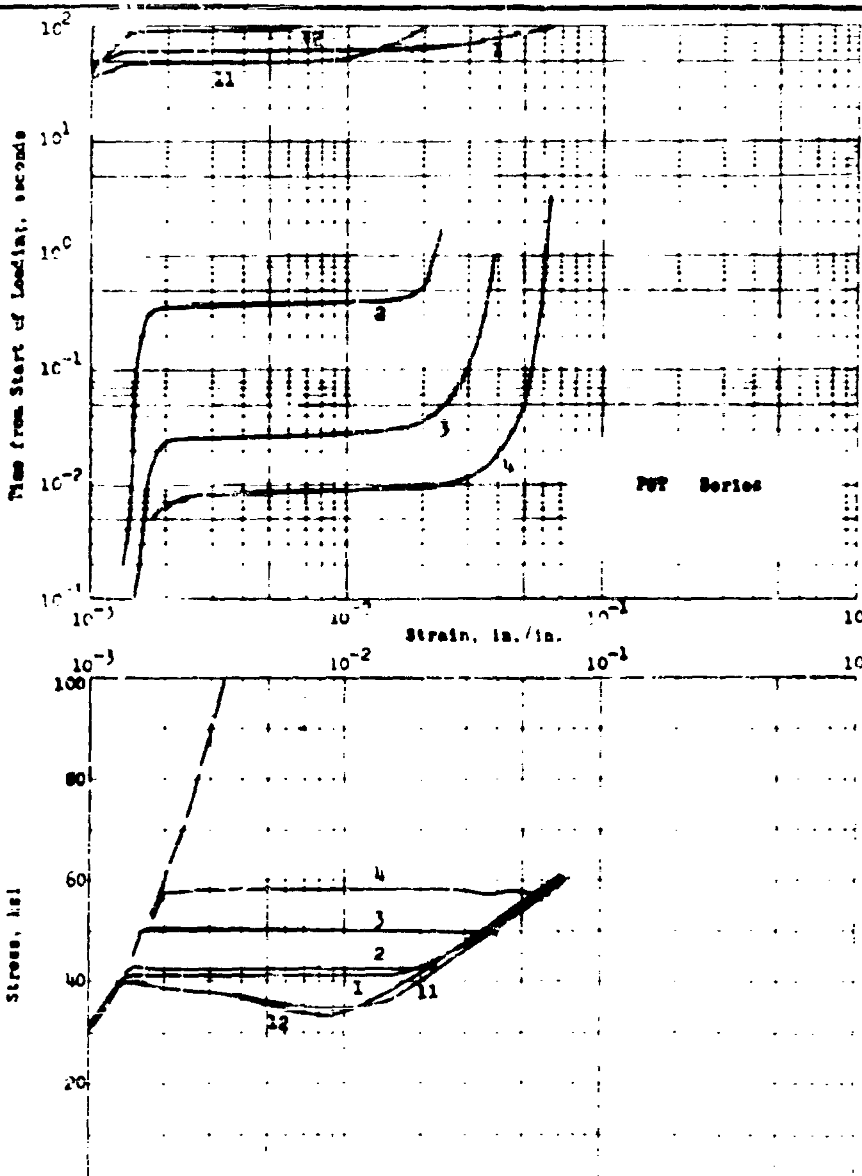


FIG. 21.3 STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

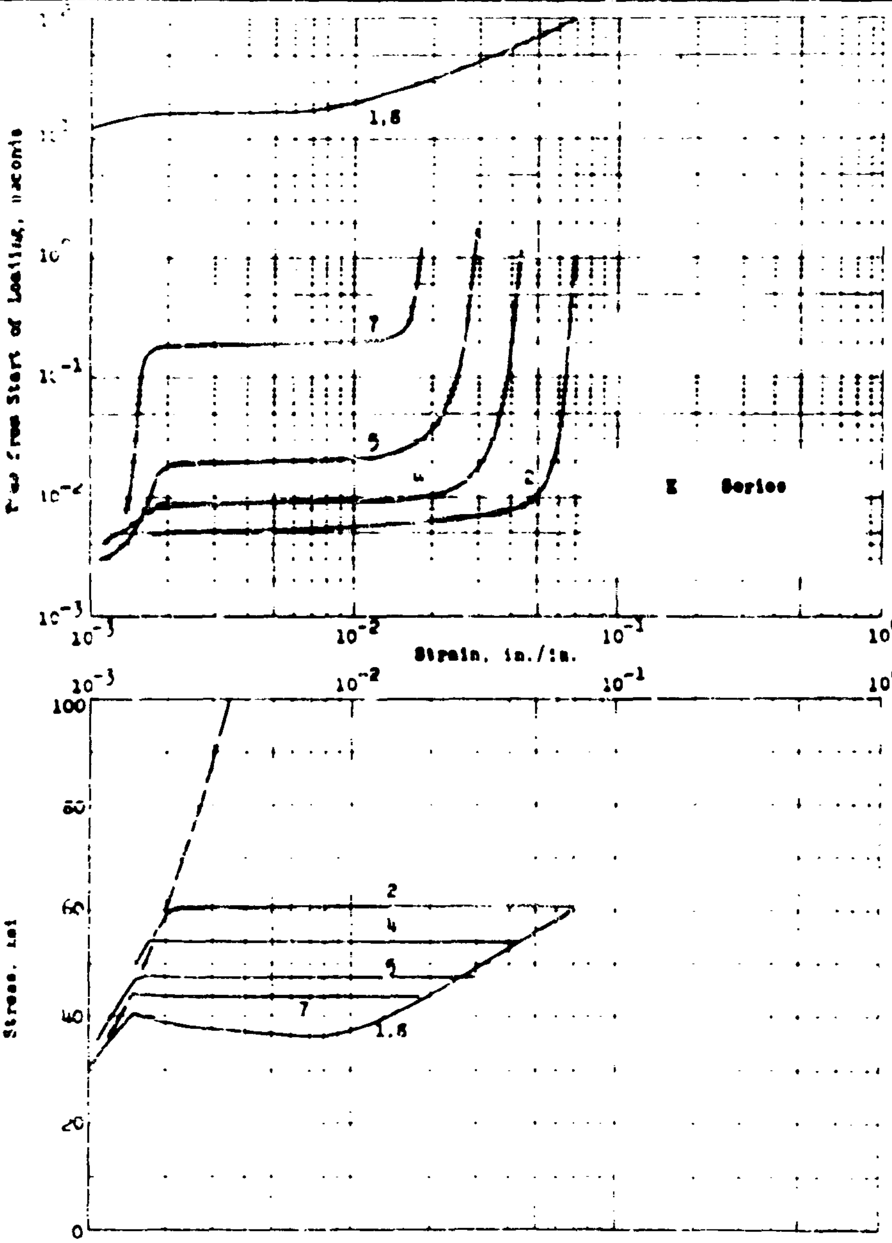
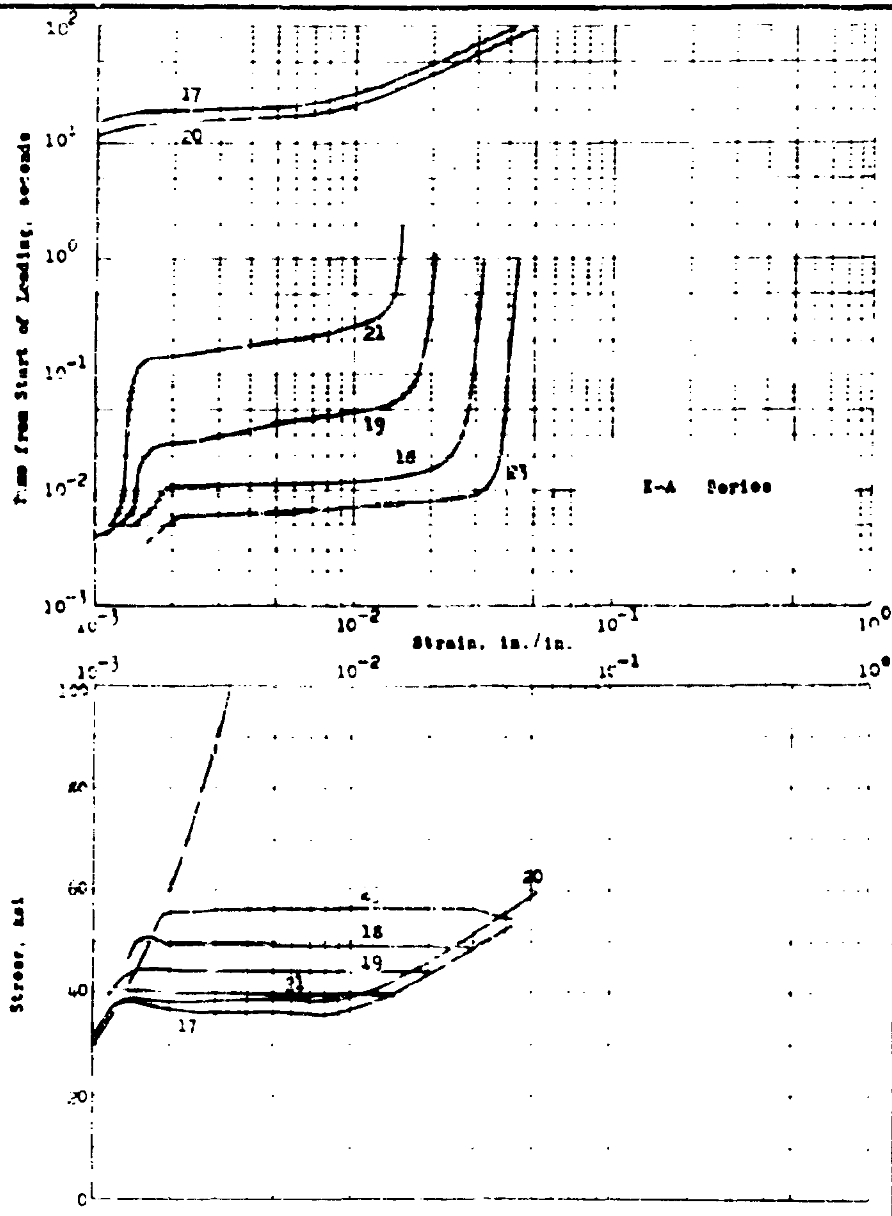


FIG. [illegible] STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS



STRESS-S..AIN AN. STRAIN-TIME RELATIONSHIPS

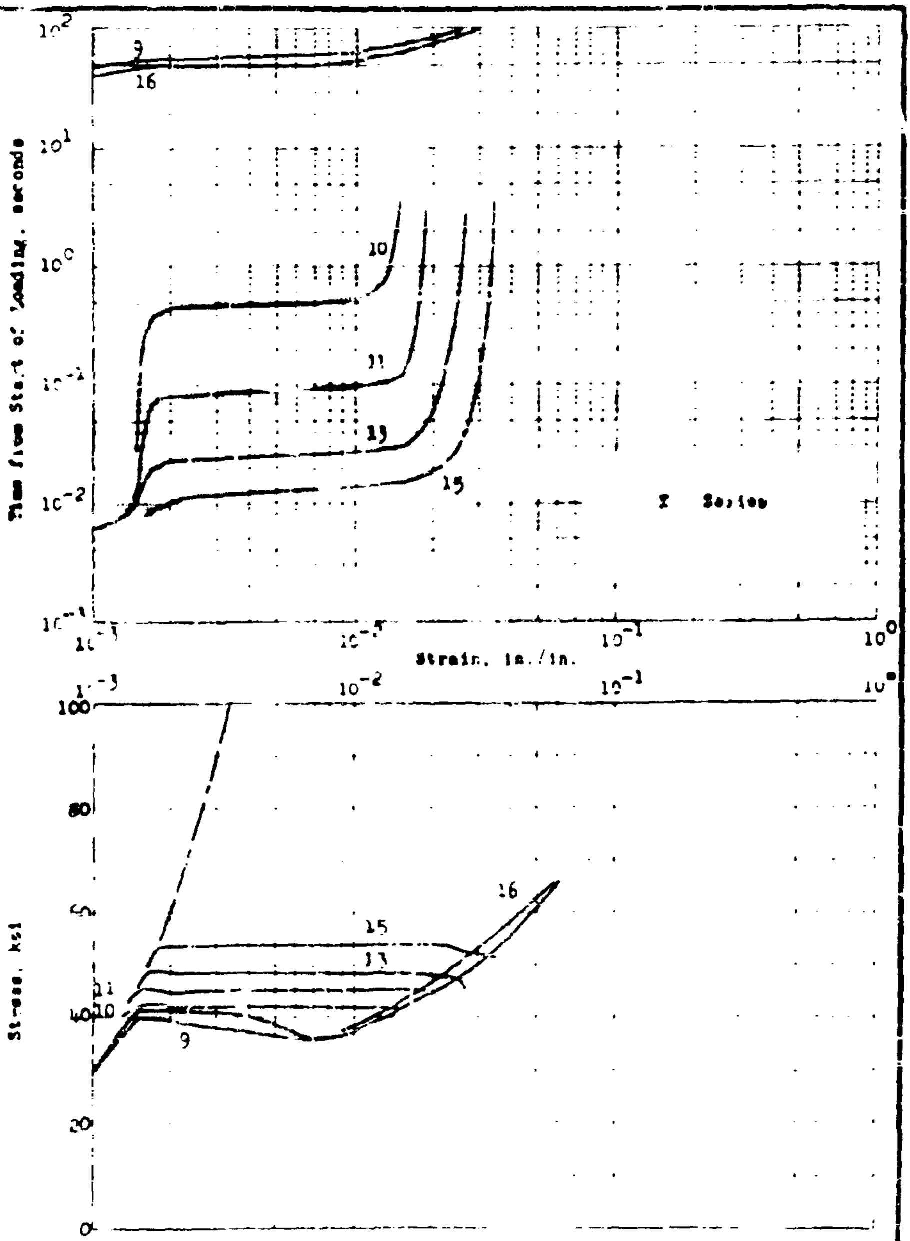


FIGURE 11. STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

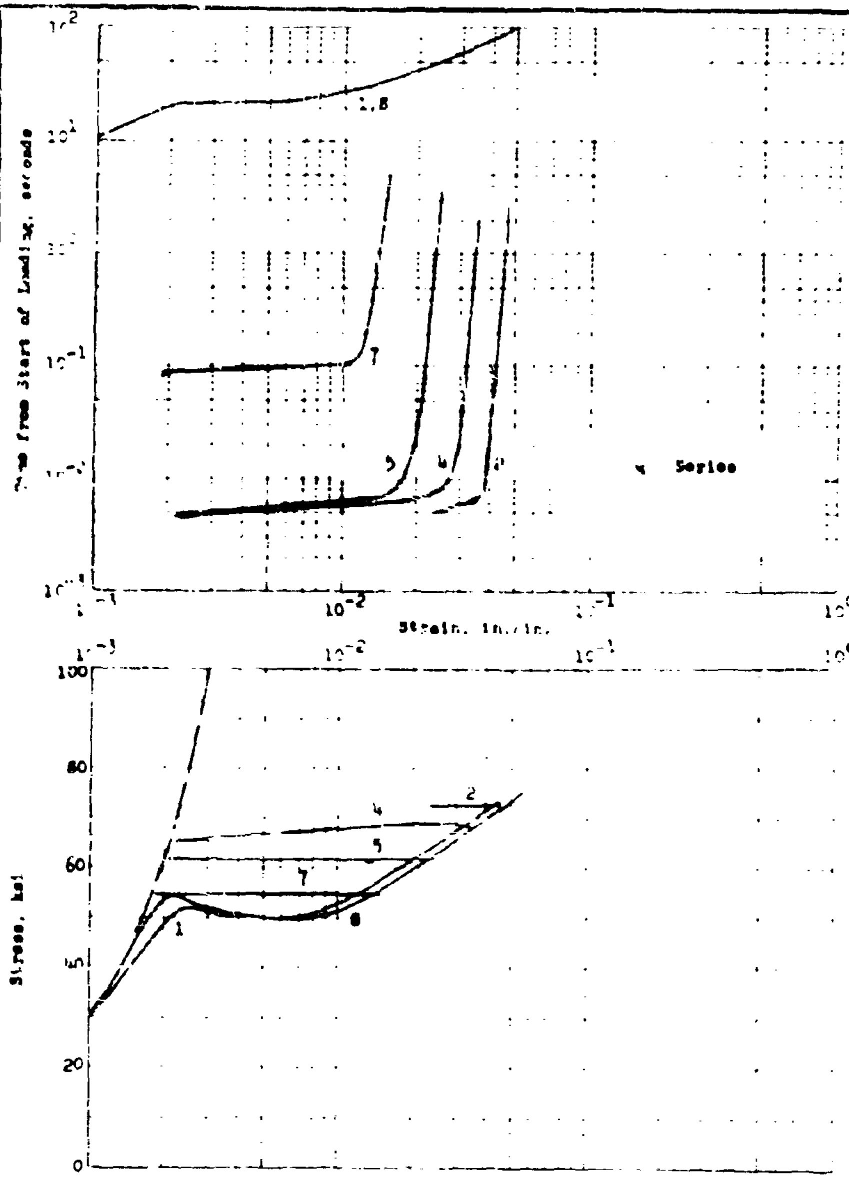


FIG. [illegible]. STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

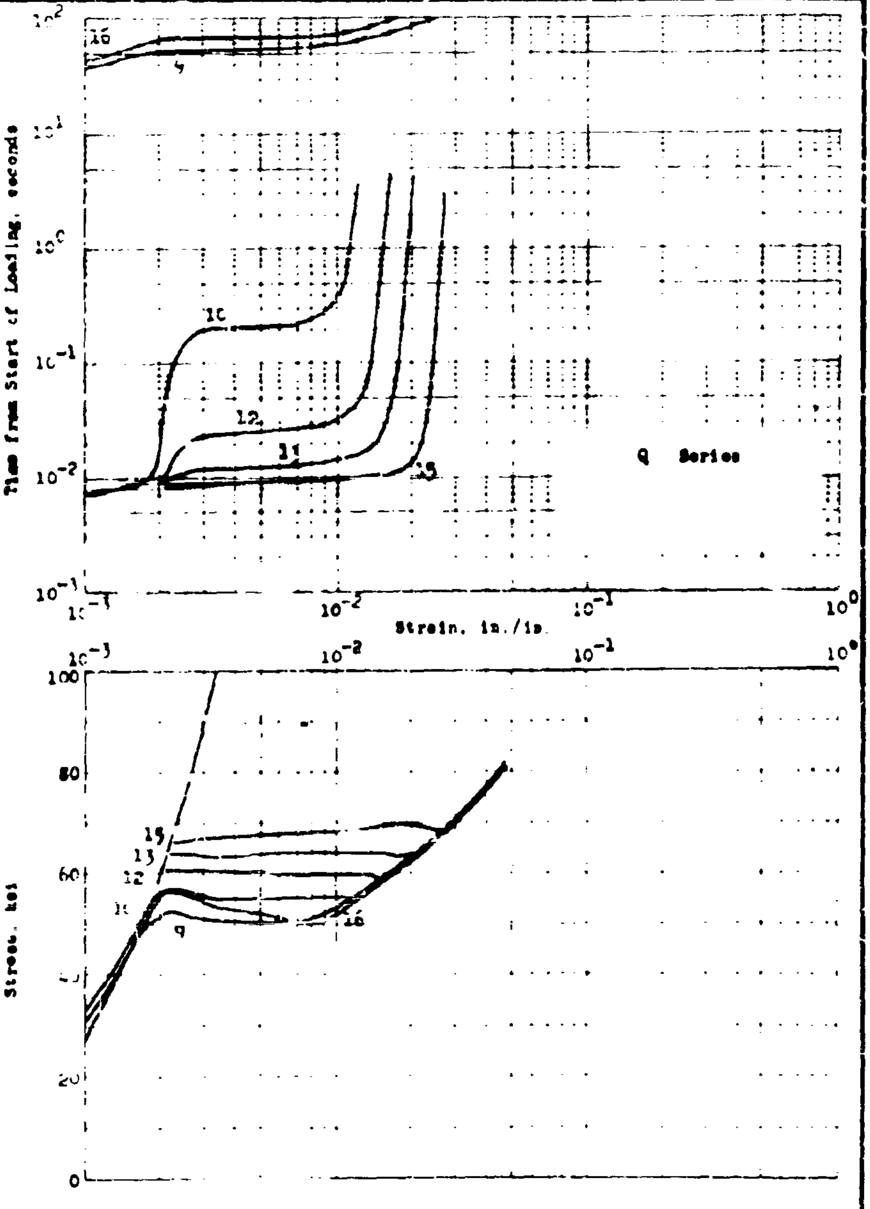


FIG. [illegible] STRESS—STRAIN AND STRAIN-TIME RELATIONSHIPS

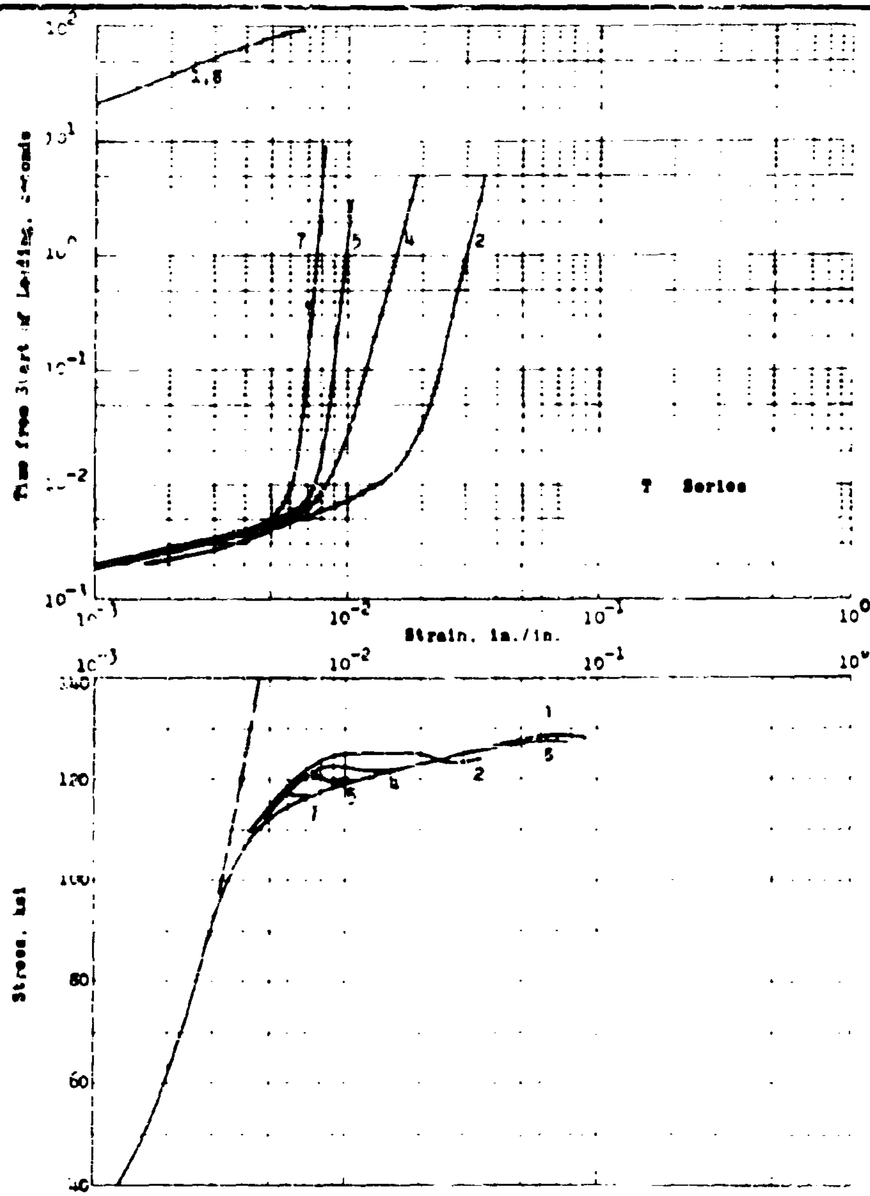


FIG. 1k STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

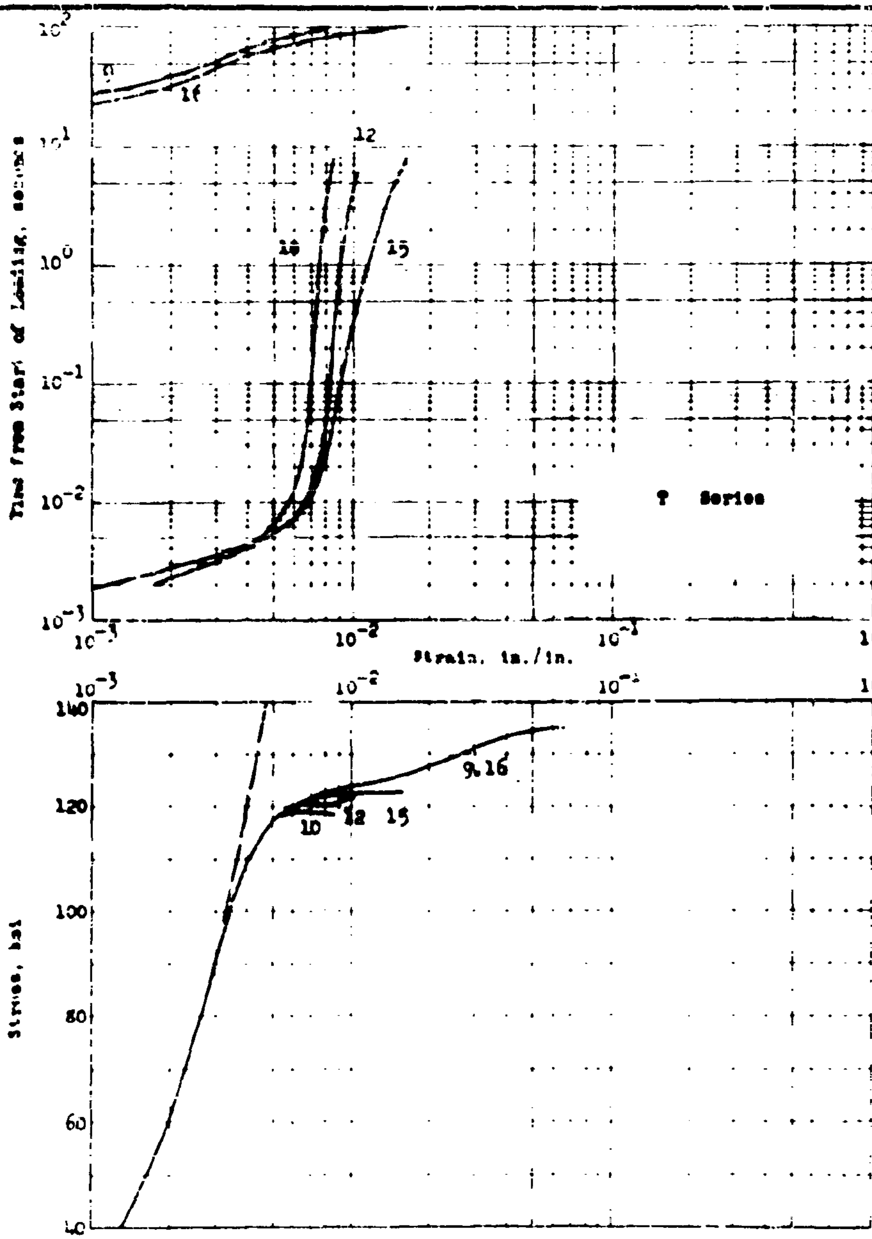


FIG. 21(STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

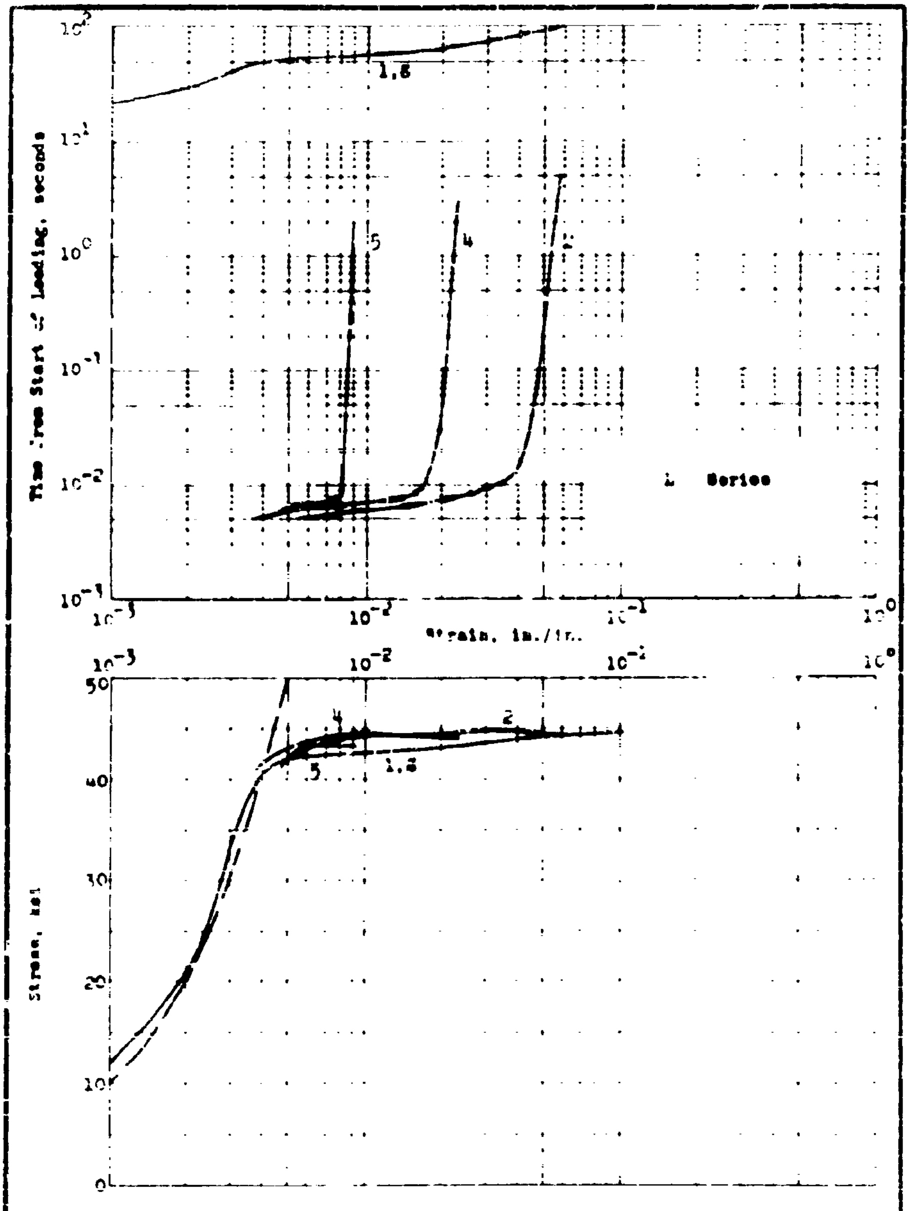


FIG. ... STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

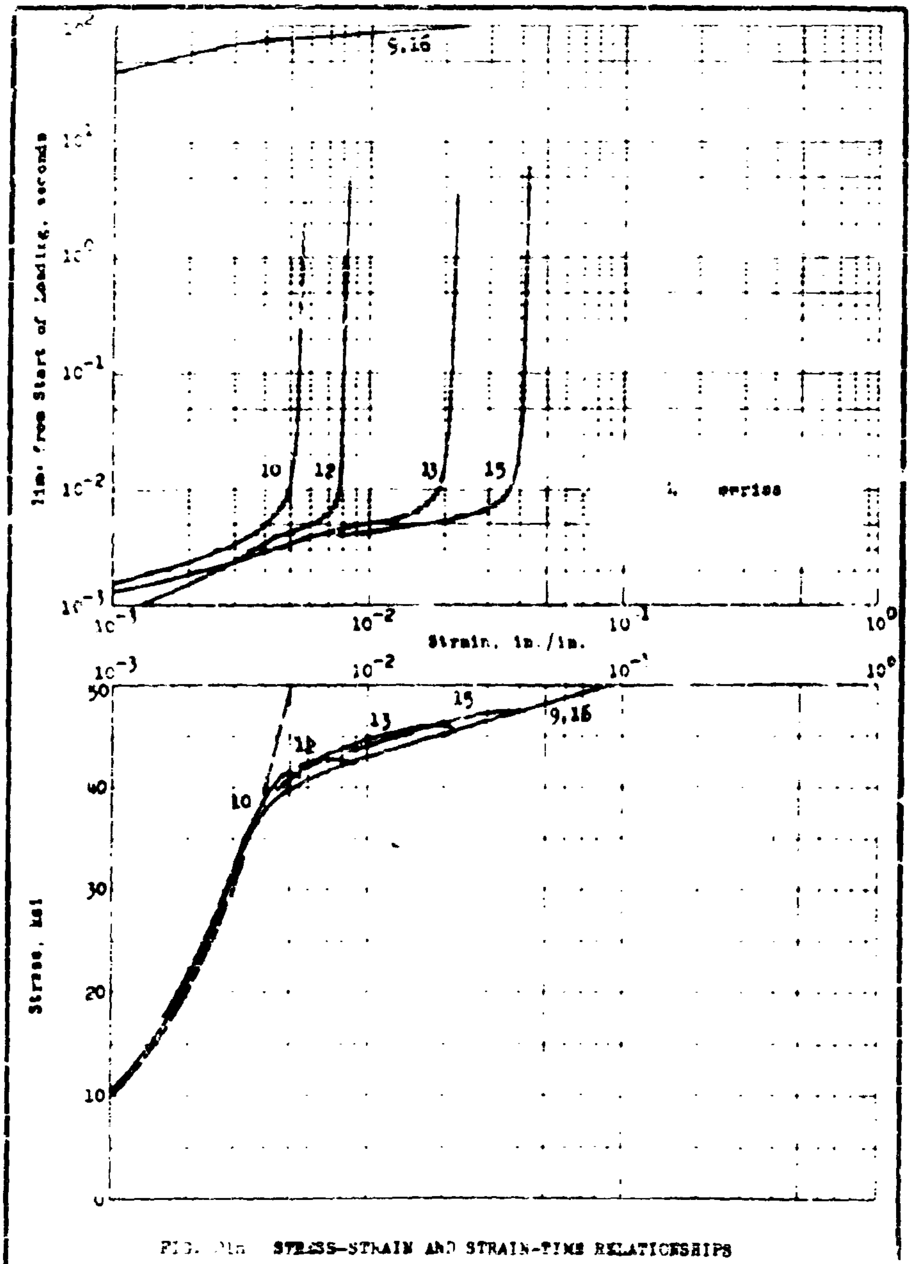


FIG. 21a STRESS—STRAIN AND STRAIN-TIME RELATIONSHIPS

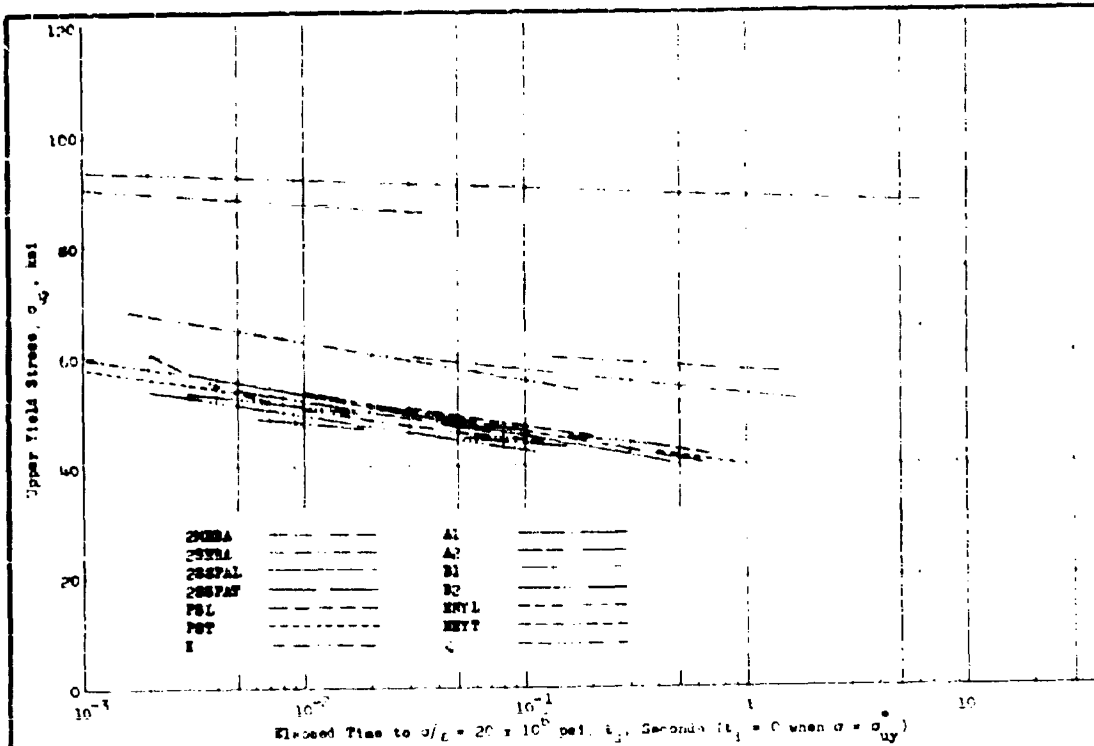


FIG. 22 UPPER YIELD STRESS - ELAPSED TIME TO σ/ε = 20 x 10^6

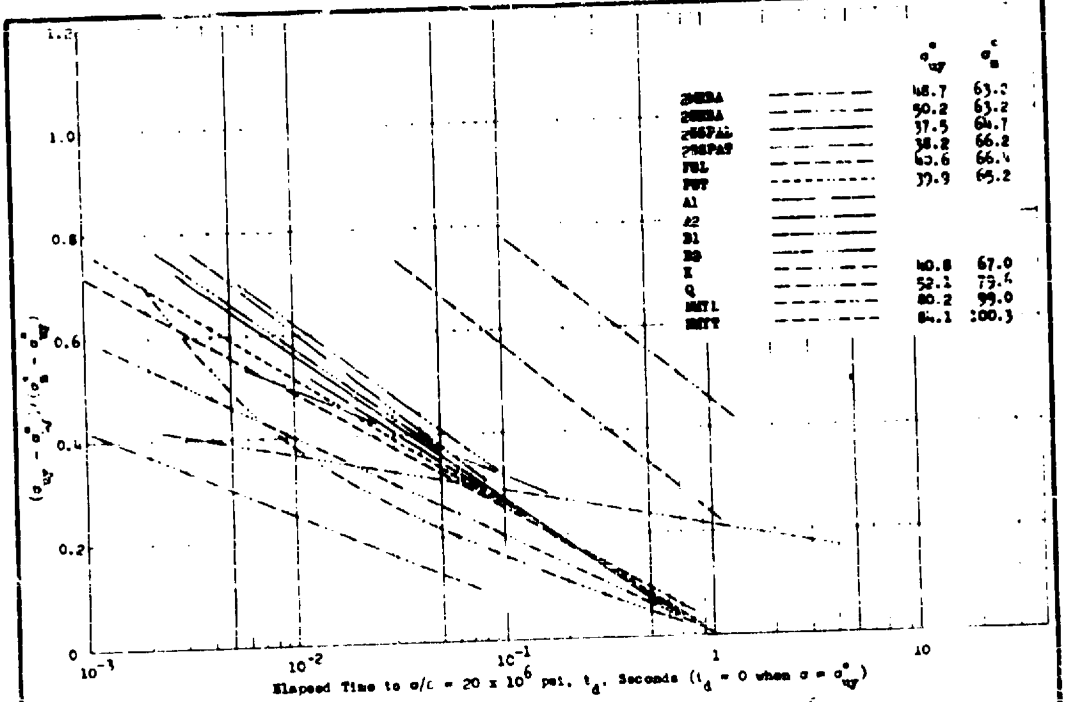


FIG. 23a UPPER YIELD STRESS PARAMETER - ELAPSED TIME TO σ/c = 20 x 10^6 psi

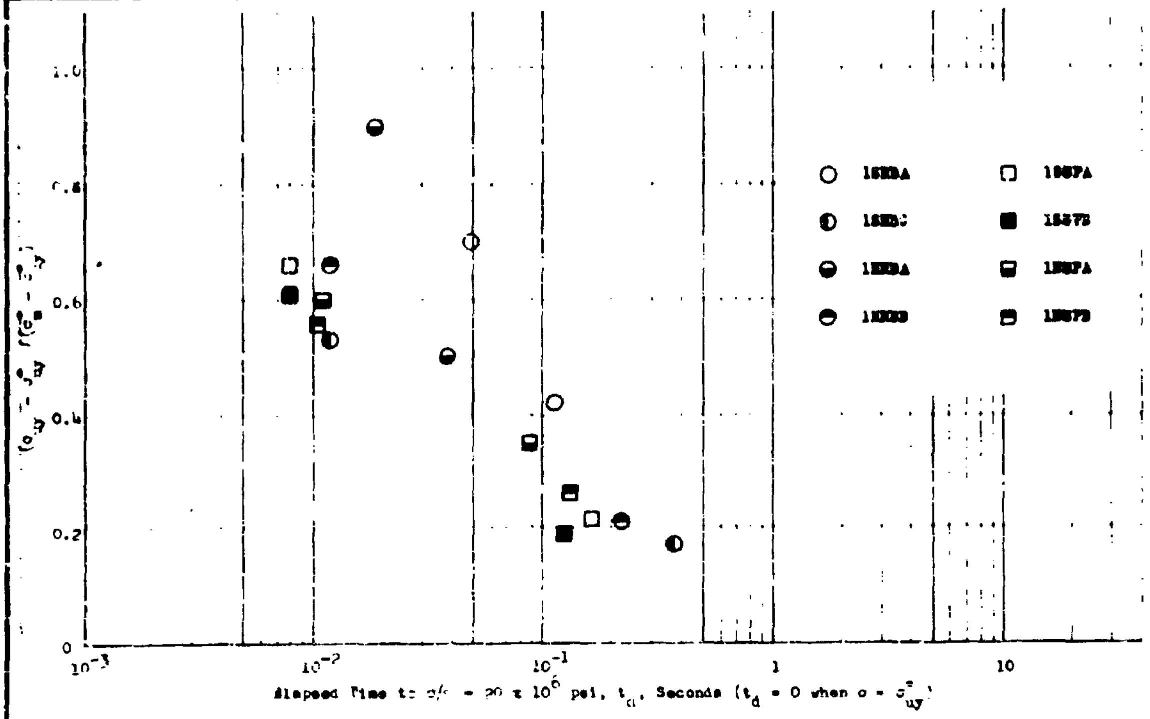


FIG. 23b YIELD STRESS PARAMETER – ELAPSED TIME TO σ/ϵ = 20 x 10^6 psi

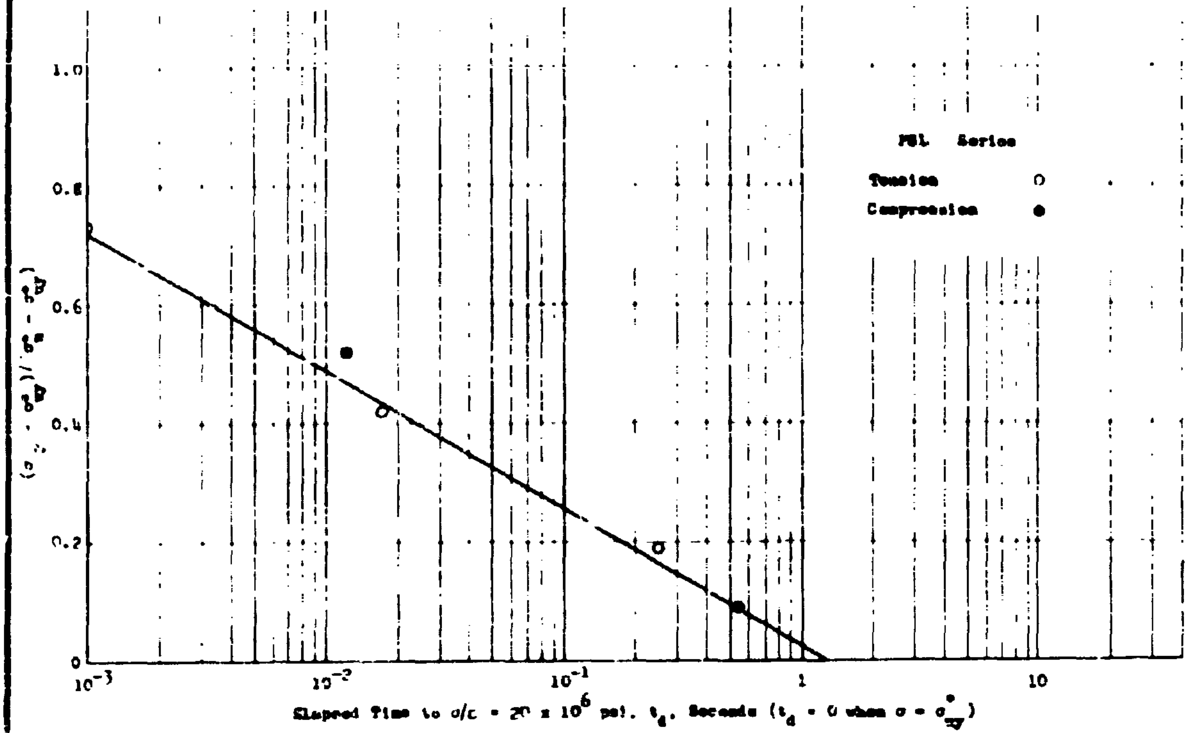


Fig. 36 YIELD STRESS PARAMETER - ELAPSED TIME TO $\sigma/\epsilon = 20 \times 10^6$ psi

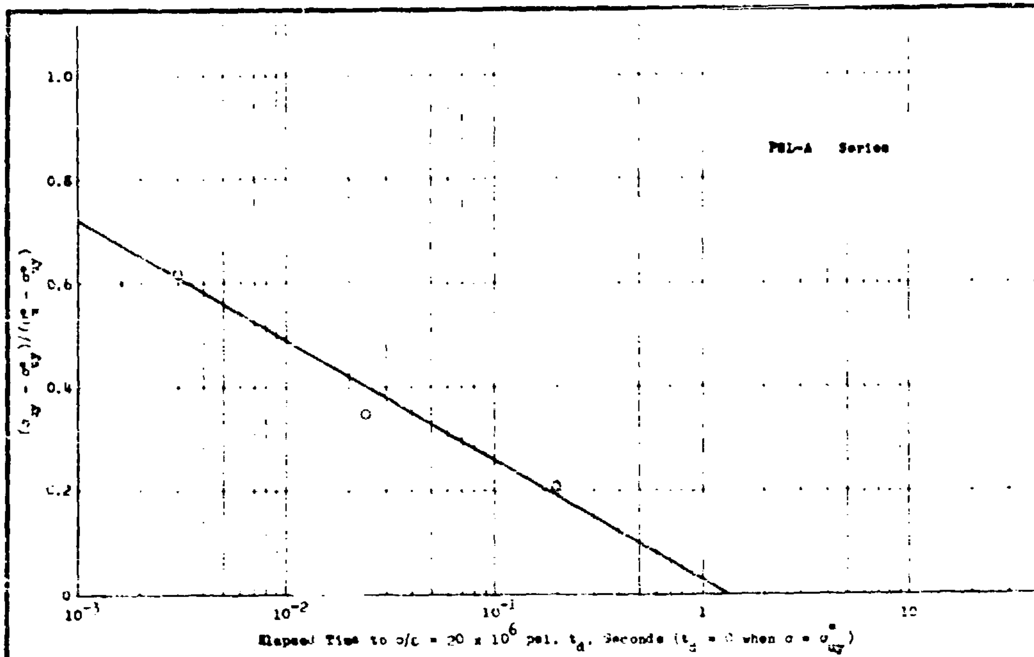


FIG. ?'d YIELD STRESS PARAMETER - ELAPSED TIME TO σ/c = 20 x 10^6 psi

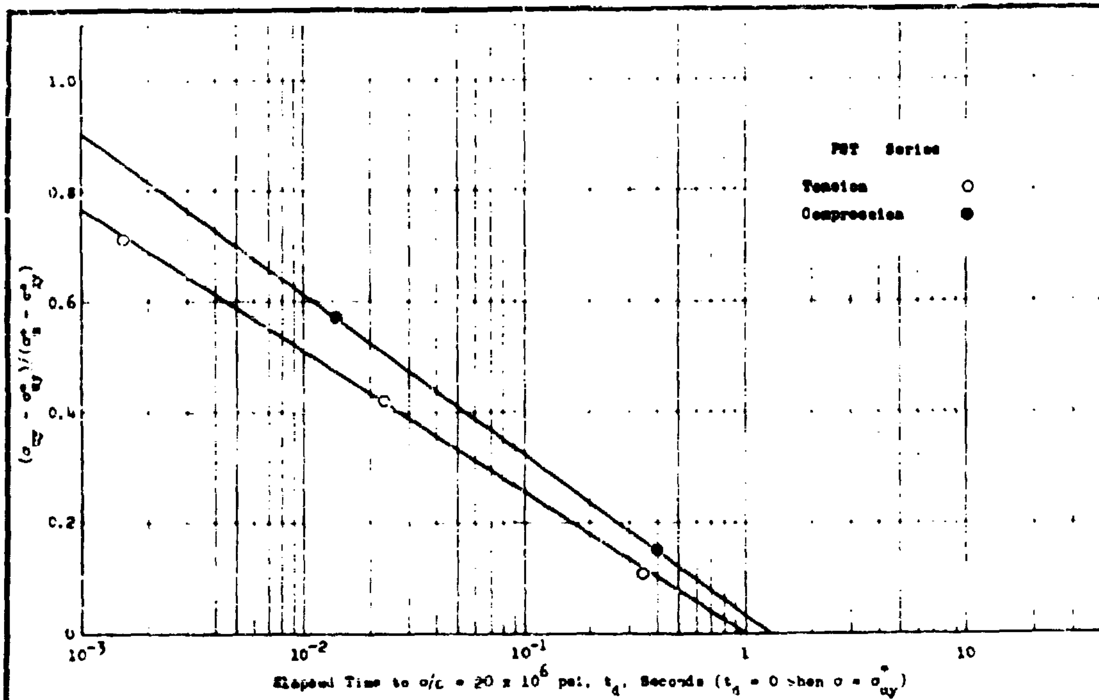


FIG. [illegible] YIELD STRESS PARAMETER - ELAPSED TIME TO σ/ϵ = 20 x 10^6 psi

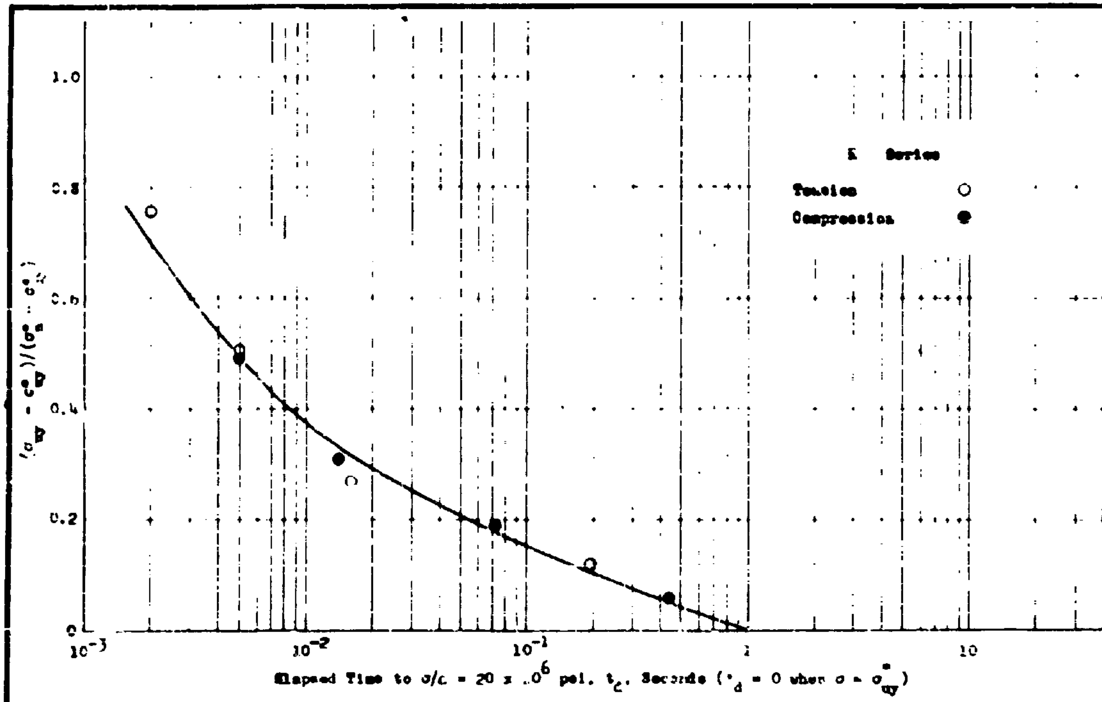


FIG. 25f YIELD STRESS PARAMETER - ELAPSED TIME TO σ/ε = 20 x 10^6 psi

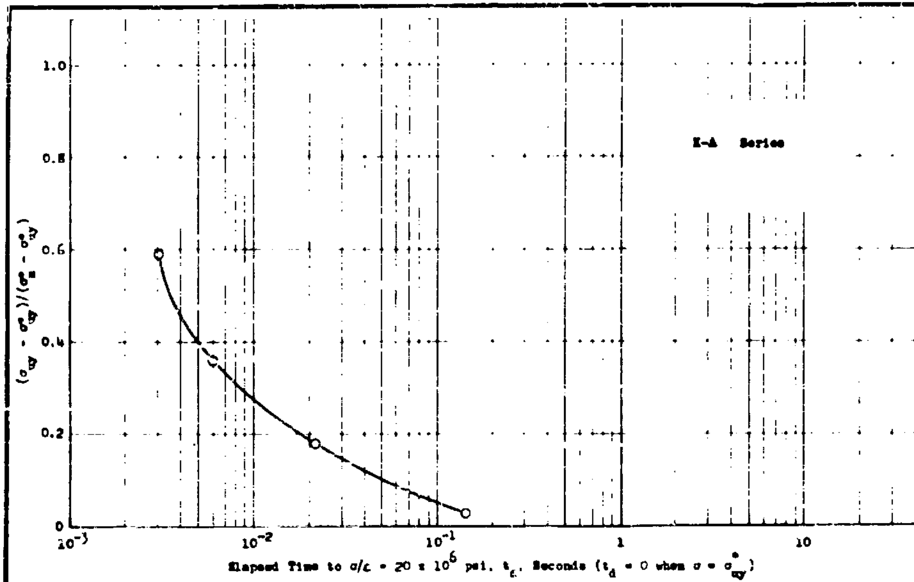


FIG. 58 YIELD STRESS PARAMETER - ELAPSED TIME TO σ/ε = 20 x 10^6 psi

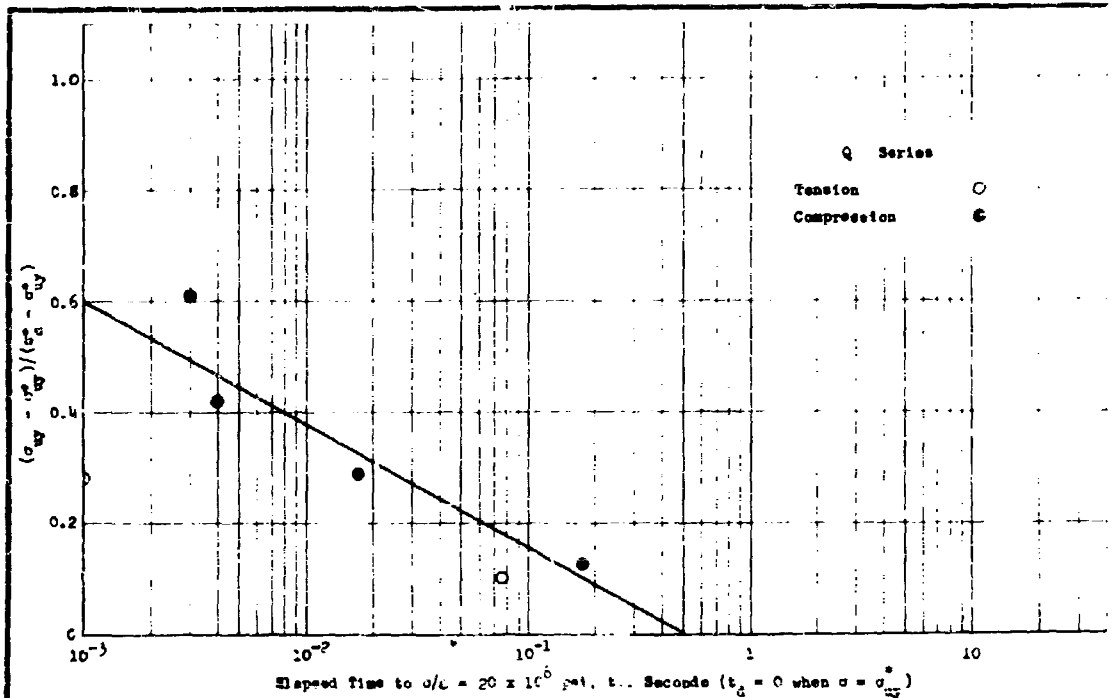


FIG. 25h YIELD STRESS PARAMETER - ELAPSED TIME TO σ/ϵ = 20 x 10^6 psi

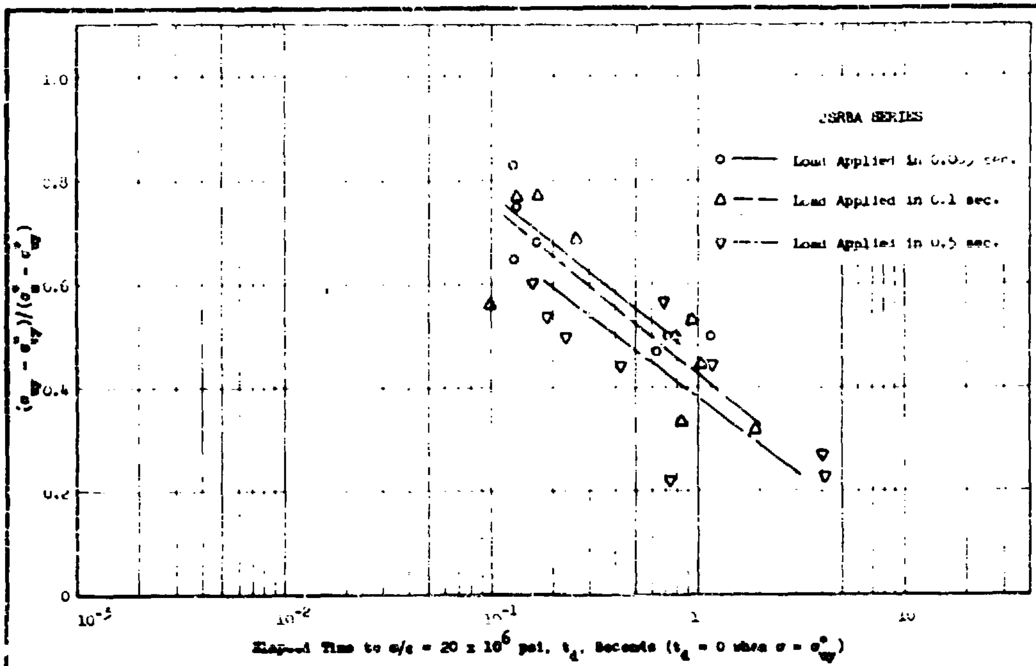


FIG. 24a YIELD STRESS PARAMETER – ELAPSED TIME TO σ/ε = 20 x 10^6 psi

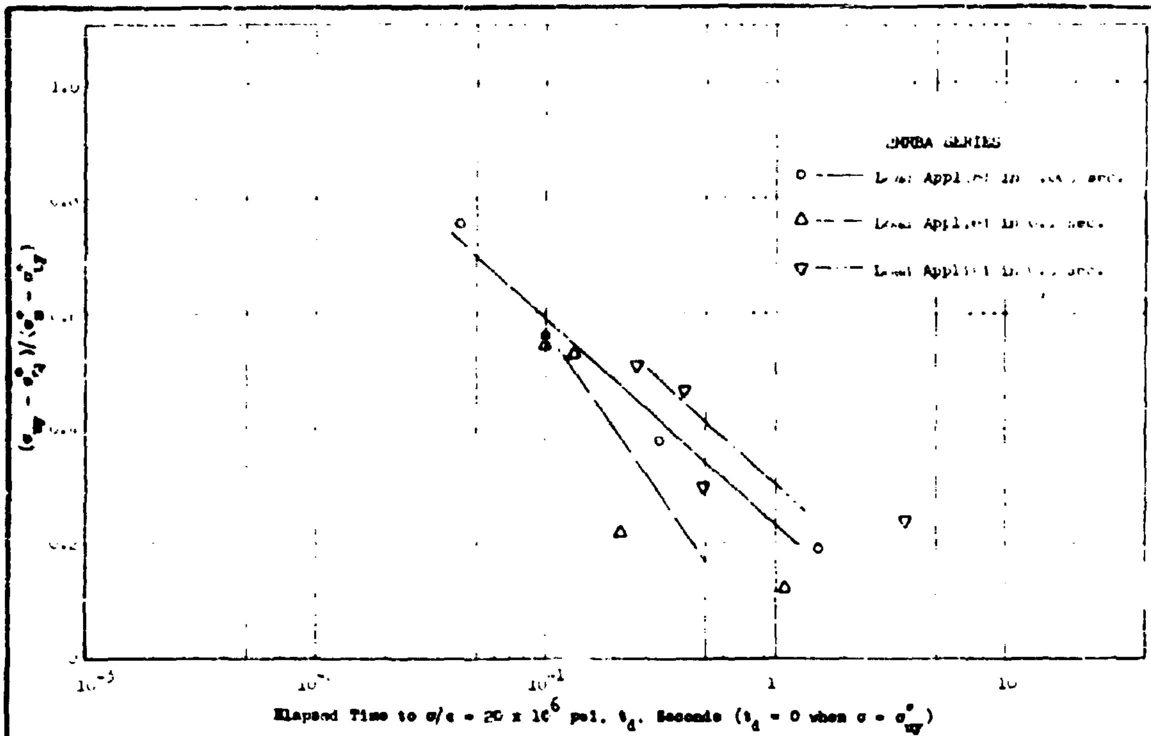


FIG. 24b YIELD STRESS PARAMETER - ELAPSED TIME TO σ/ϵ = 20 x 10^6 psi

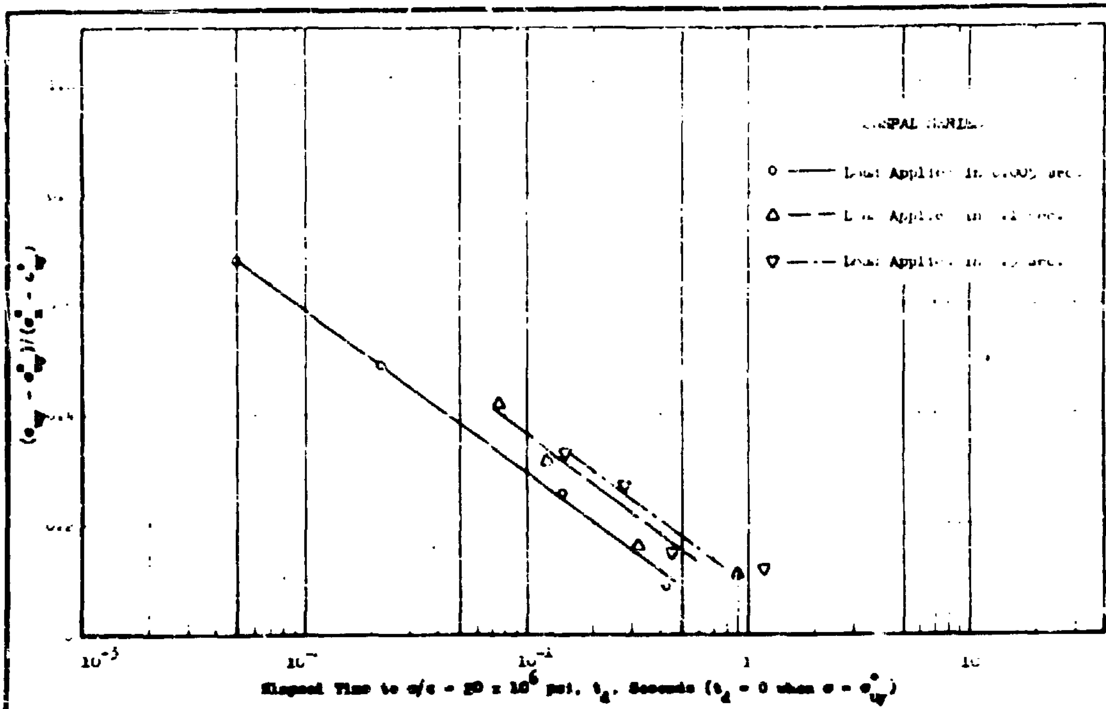


FIG. 24c YIELD STRESS PARAMETER – ELAPSED TIME TO σ/ε = 20 x 10^6 psi

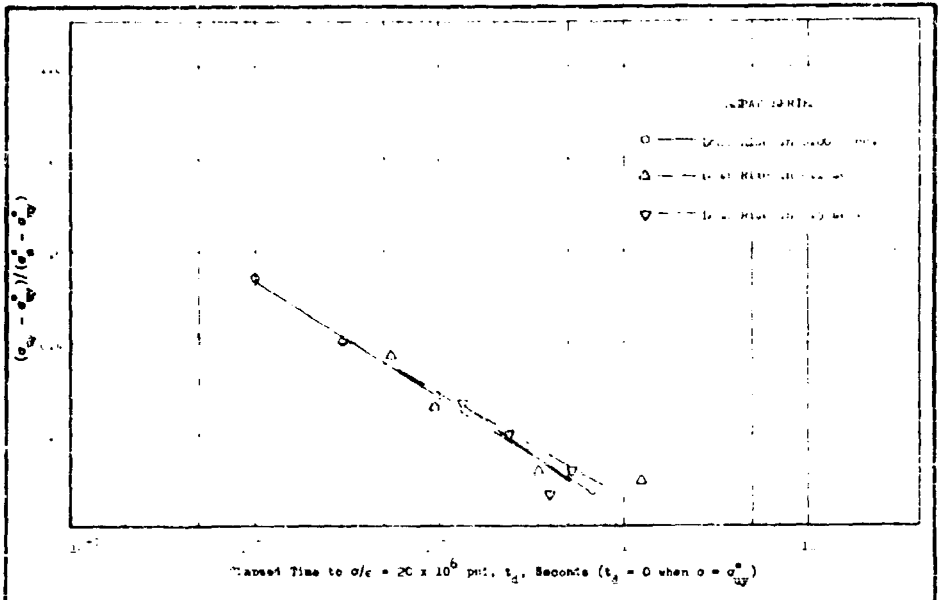


FIG. 26d YIELD STRESS PARAMETER - ELAPSED TIME TO $\sigma/\epsilon = 20 \times 10^6$ psi

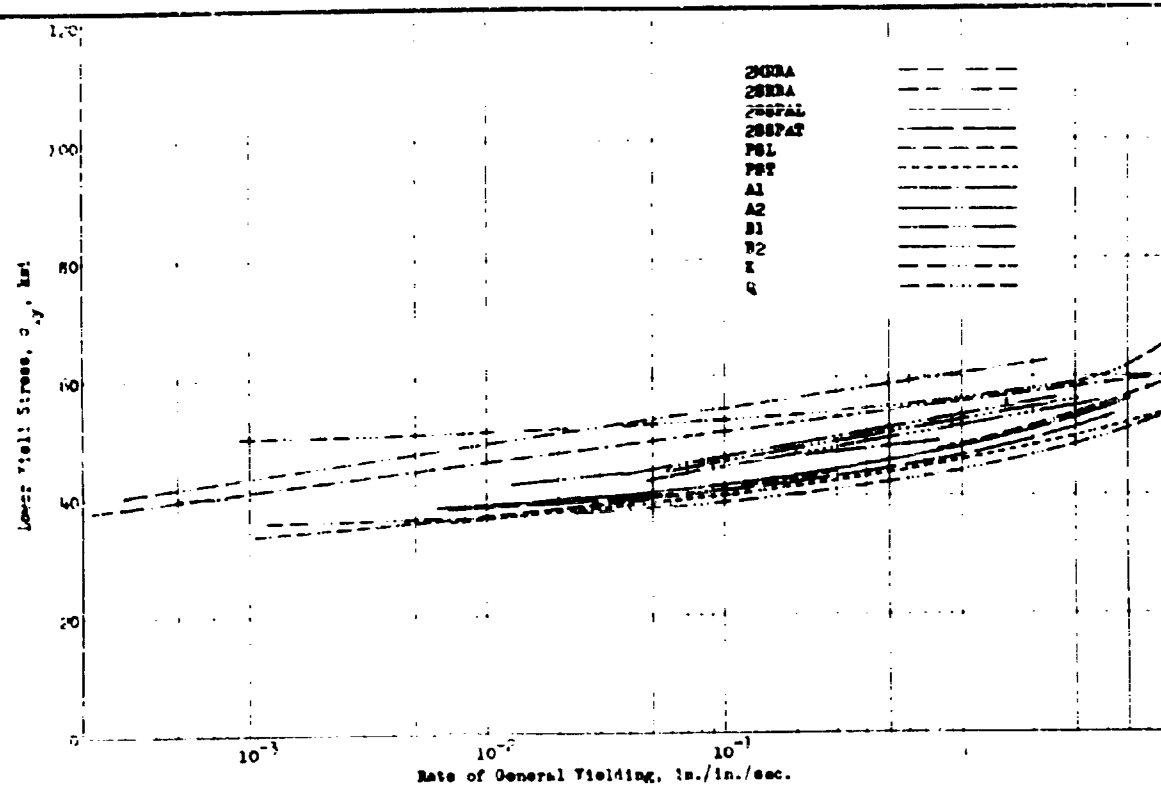


FIG. 25 LOWER YIELD STRESS - RATE OF GENERAL YIELDING

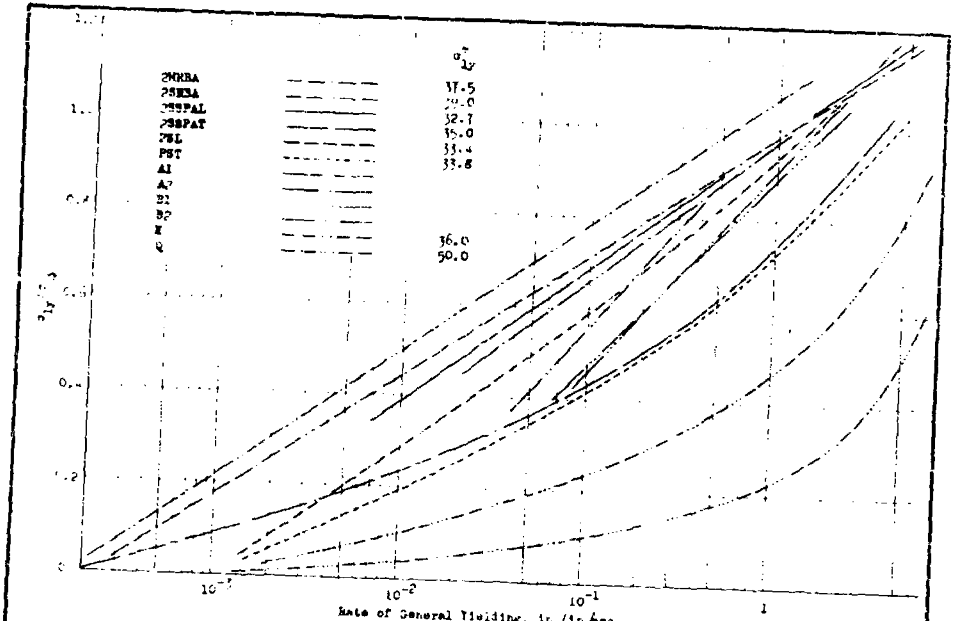


FIG. 26a LOWER YIELD STRESS PARAMETER - RATE OF GENERAL YIELDING

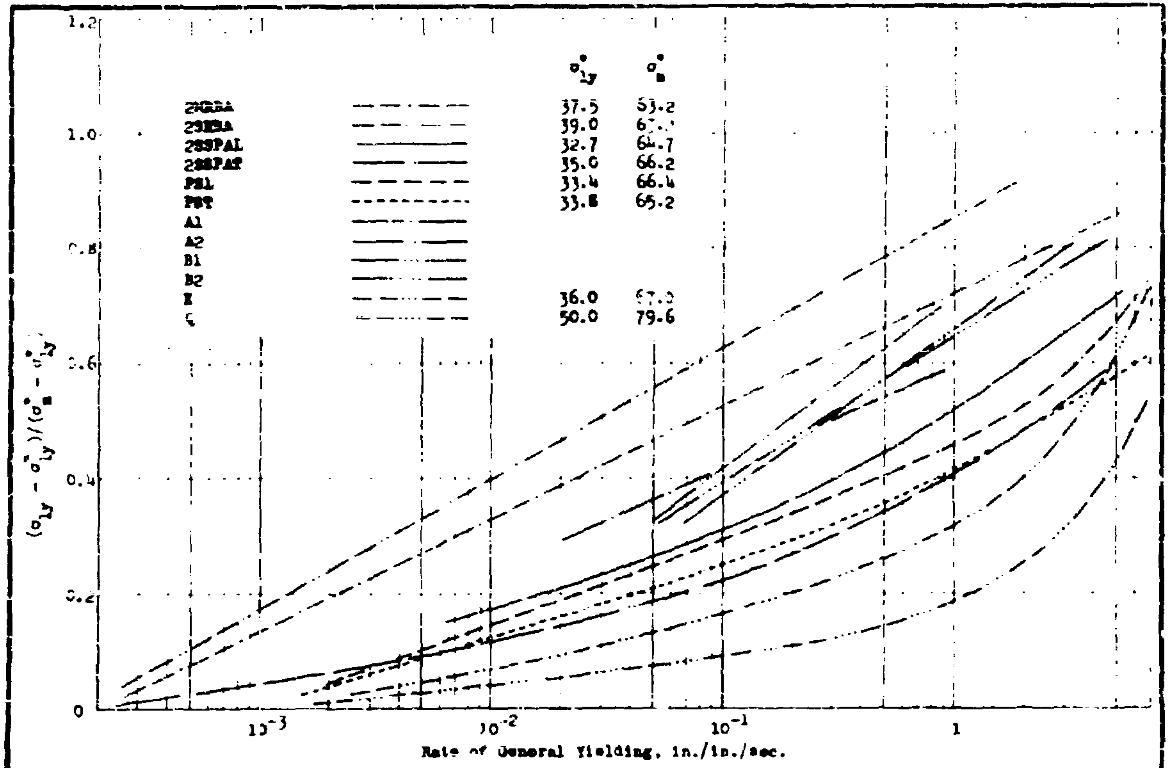


FIG. 26b LOWER YIELD STRESS PARAMETER - RATE OF GENERAL YIELDING

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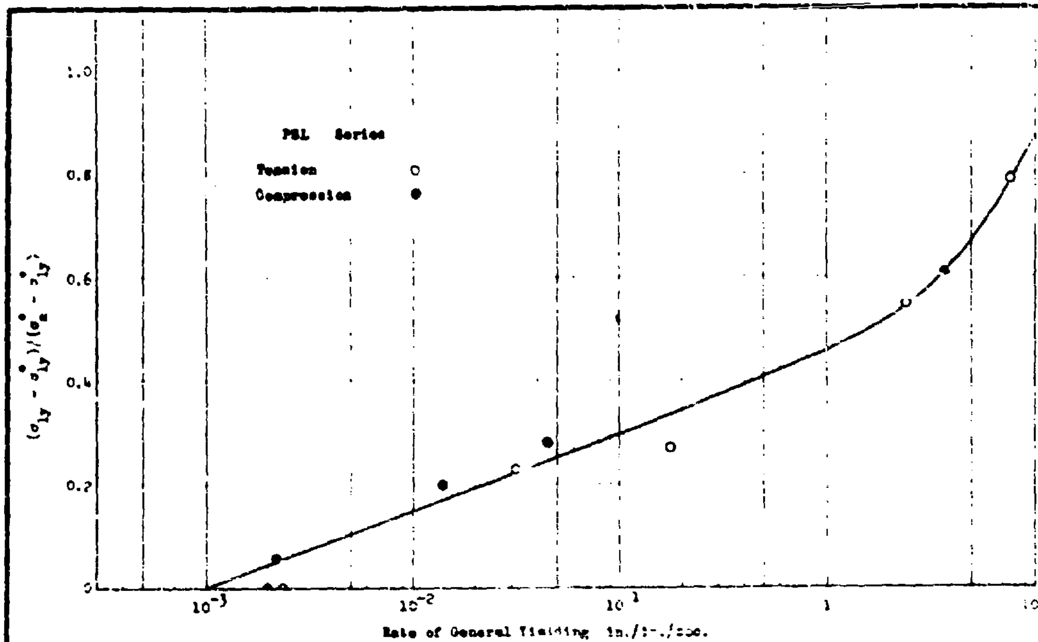


FIG. 26c YIELD STRESS PARAMETER - RATE OF YIELDING AT CONSTANT STRESS

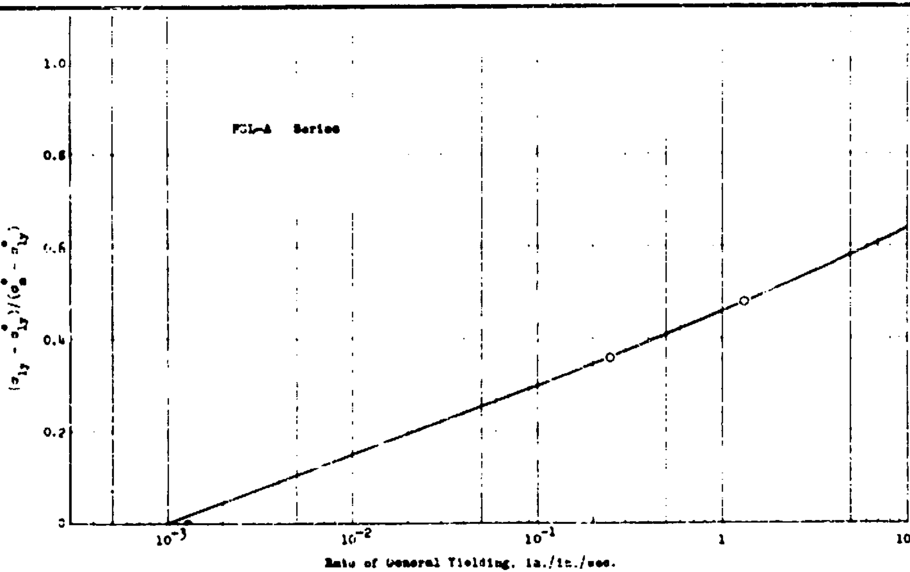


FIG. 26d YIELD STRESS PARAMETER - RATE OF YIELDING AT CONSTANT STRESS

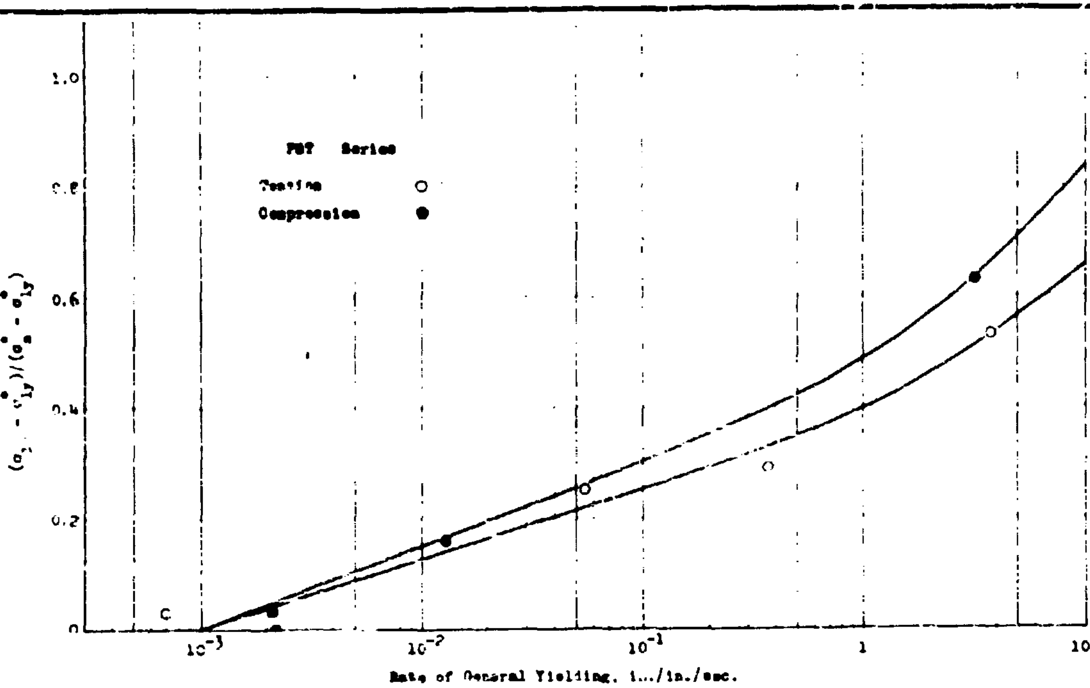


FIG. 26e YIELD STRESS PARAMETER RATE OF YIELDING AT CONSTANT STRESS

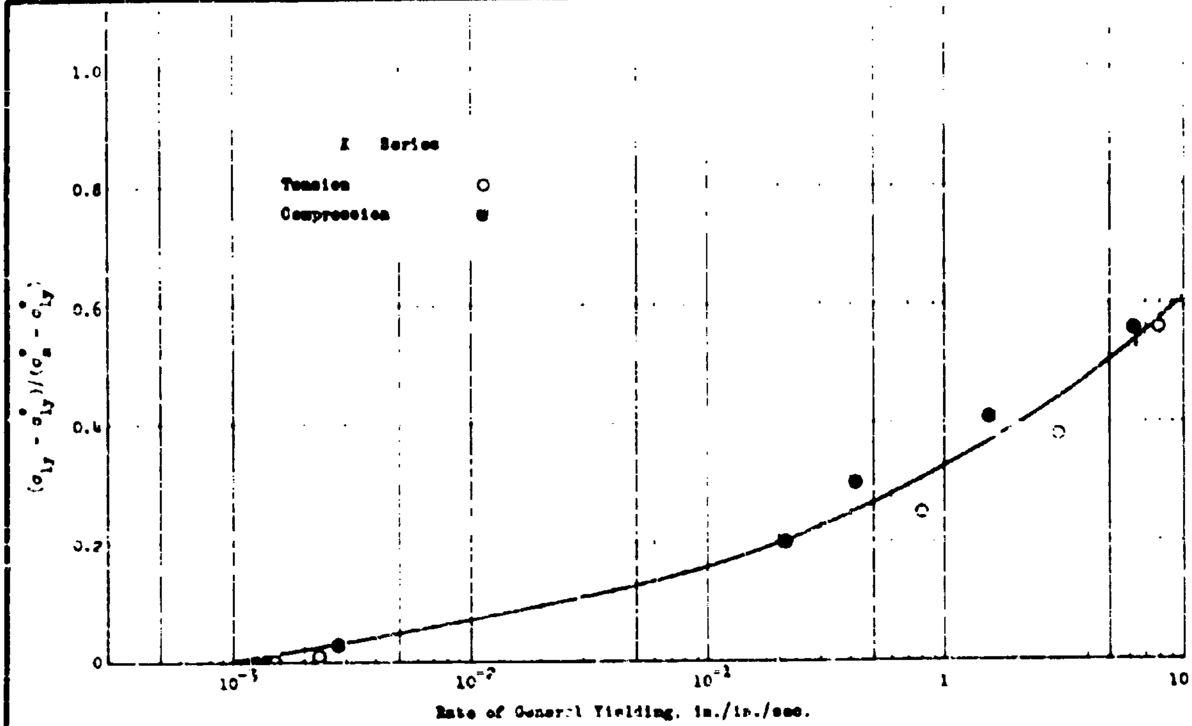


FIG. 26f YIELD STRESS PARAMETER - RATE OF YIELDING AT CONSTANT STRESS

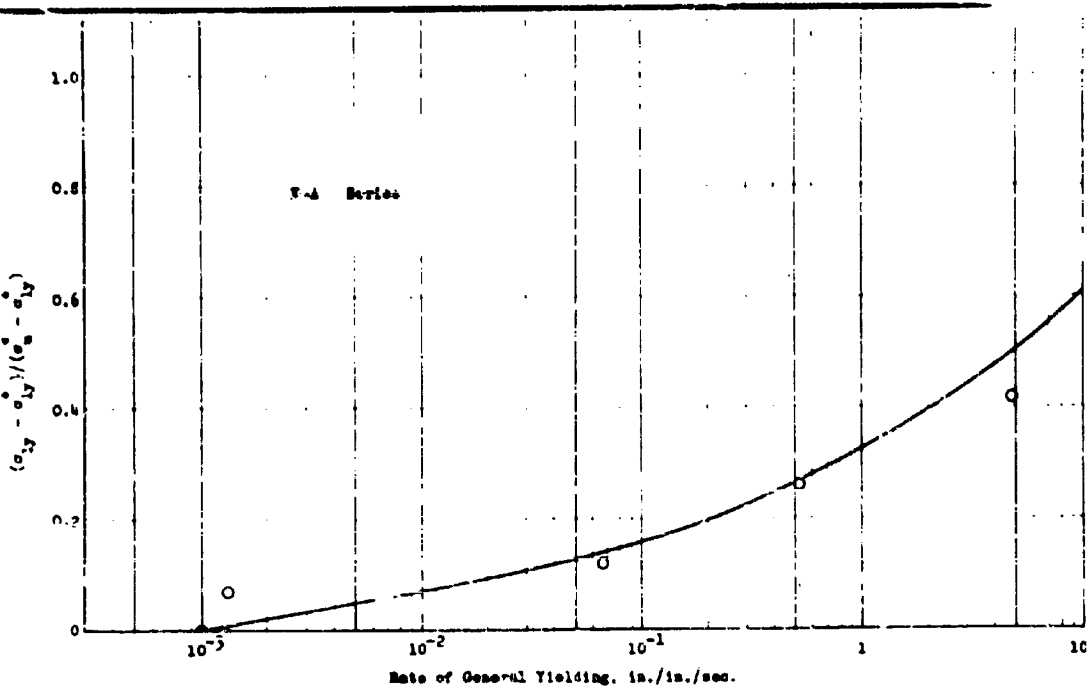


FIG. 26g YIELD STRESS PARAMETER - RATE OF YIELDING AT CONSTANT STRESS

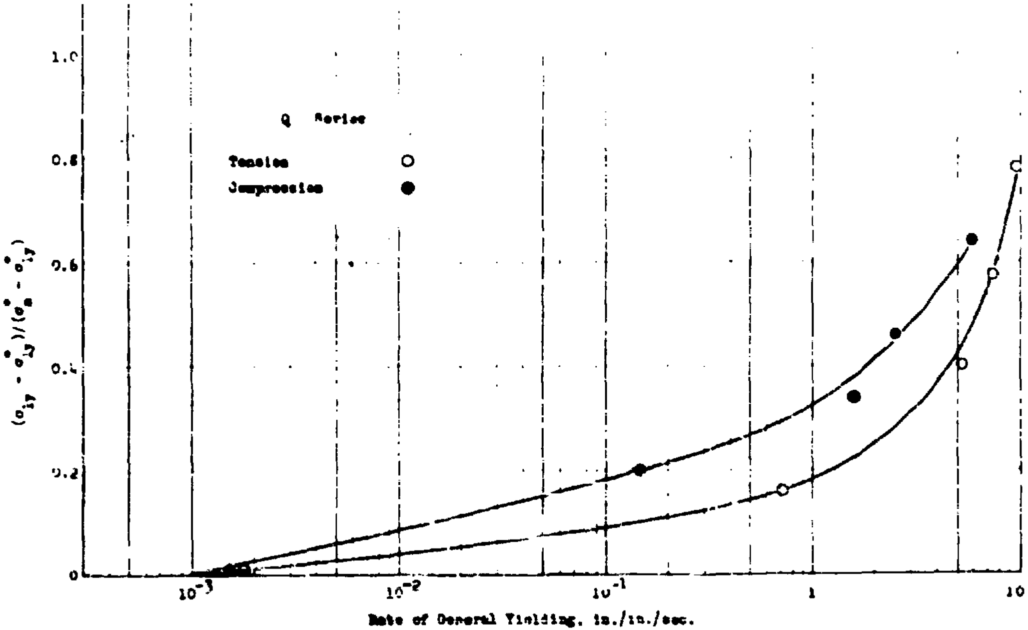


FIG. [illegible] YIELD STRESS PARAMETER - RATE OF YIELDING AT CONSTANT STRESS

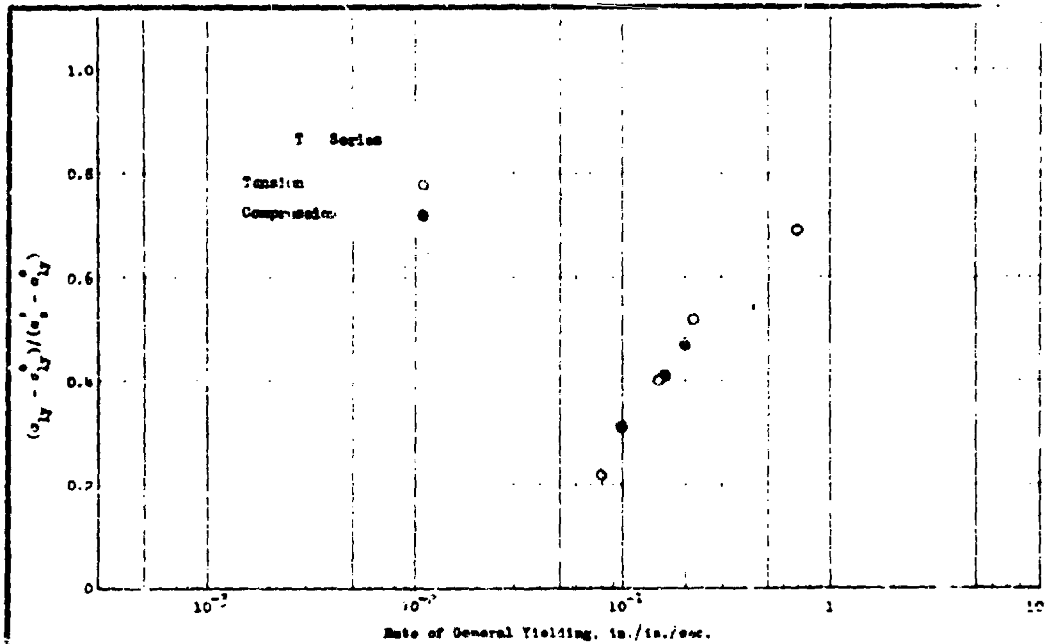


FIG. 261 YIELD STRESS PARAMETER - RATE OF YIELDING AT CONSTANT STRESS

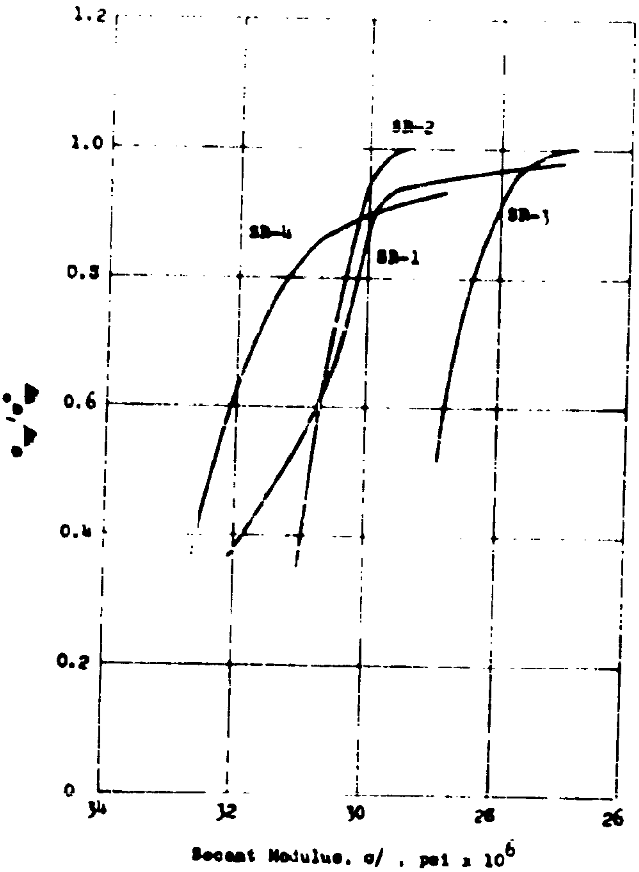


FIG. 27 UPPER YIELD STRESS PARAMETER - SECANT MODULUS

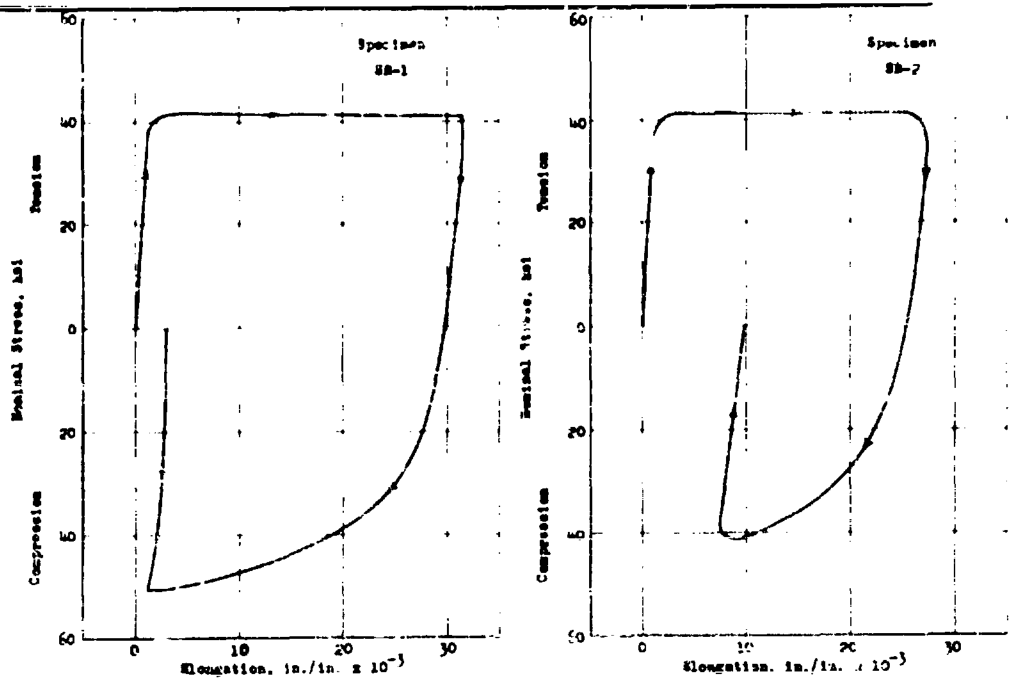


FIG. 28a NOMINAL STRESS - ELONGATION; SLOW LOADING WITH REVERSAL

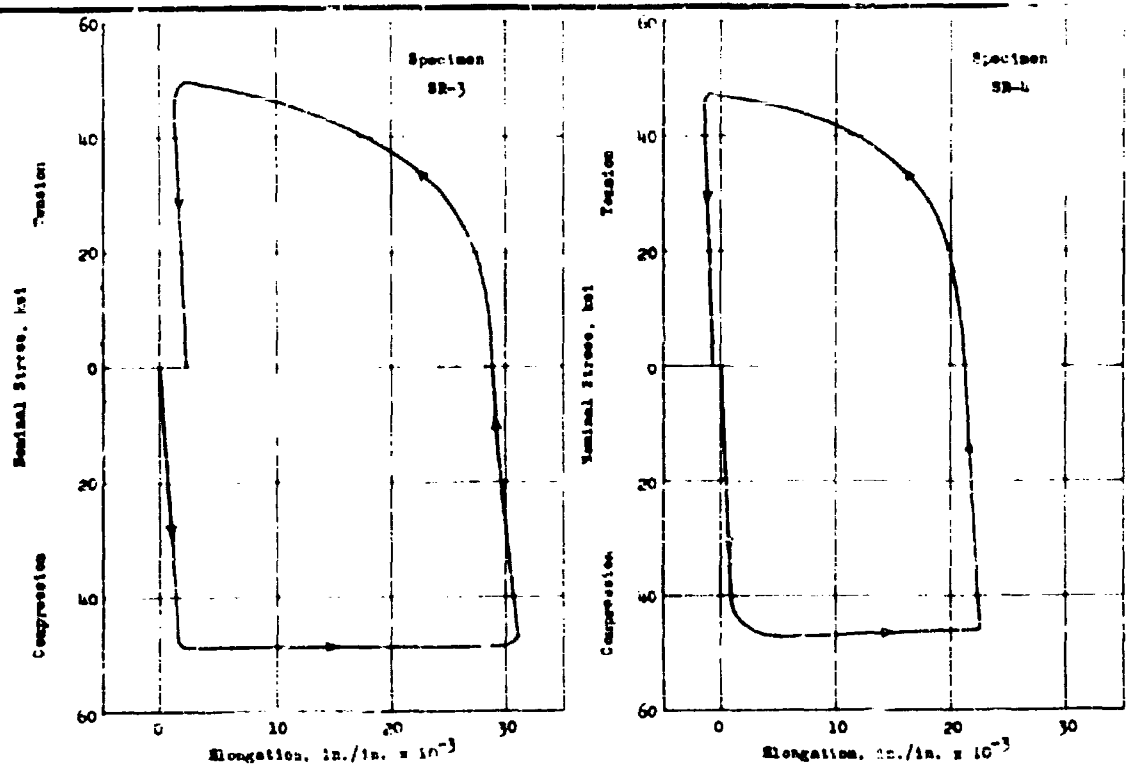


FIG. 28b NOMINAL STRESS - ELONGATION; SLOW LOADING WITH REVERSAL

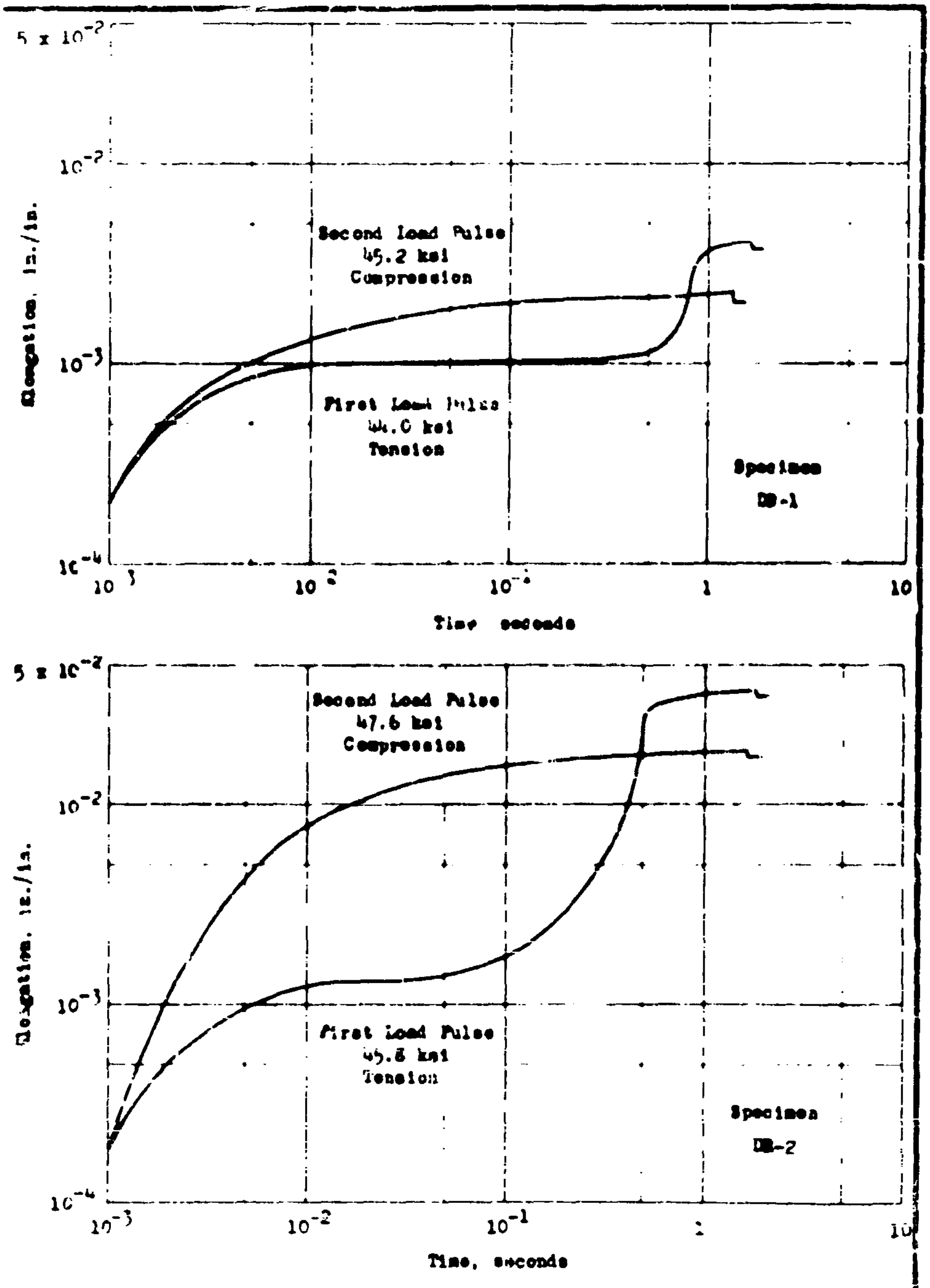


FIG. 29a ELONGATION - TIME; RAPID LOADING WITH REVERSAL

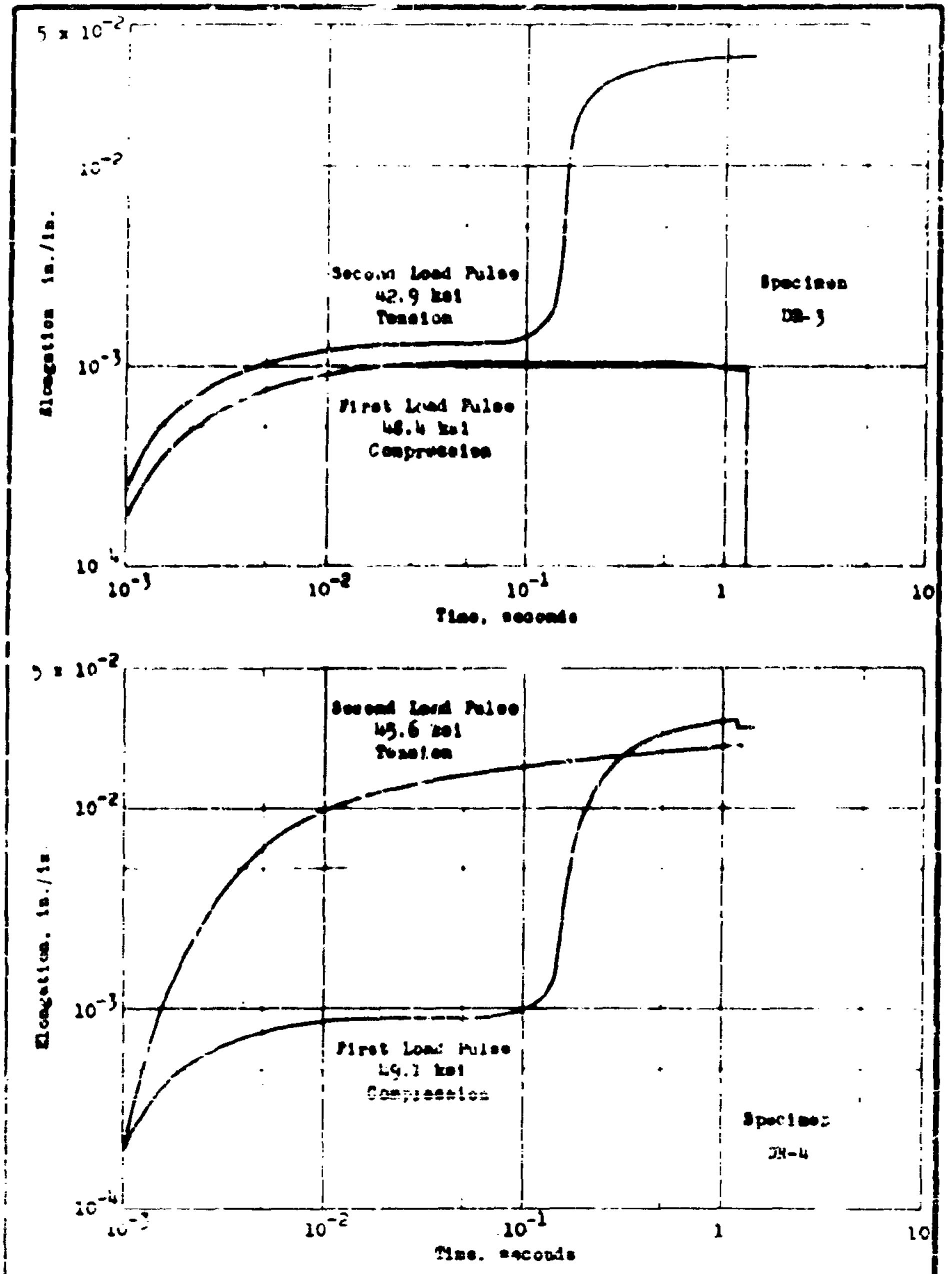


FIG. 29b ELONGATION - TIME; RAPID LOADING WITH REVERSAL

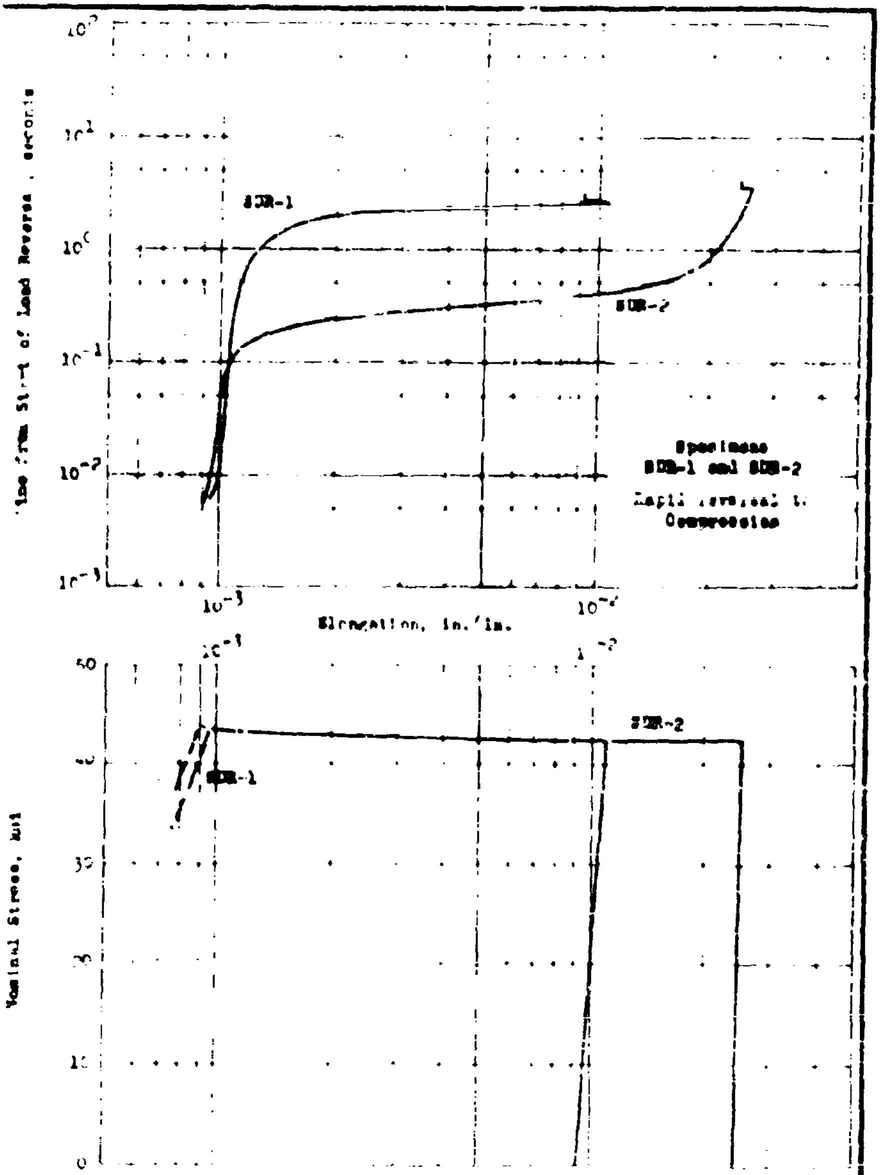


FIG. 30a STRESS - ELONGATION AND ELONGATION - TIME, RAPID REVERSAL FROM STATIC STRESS

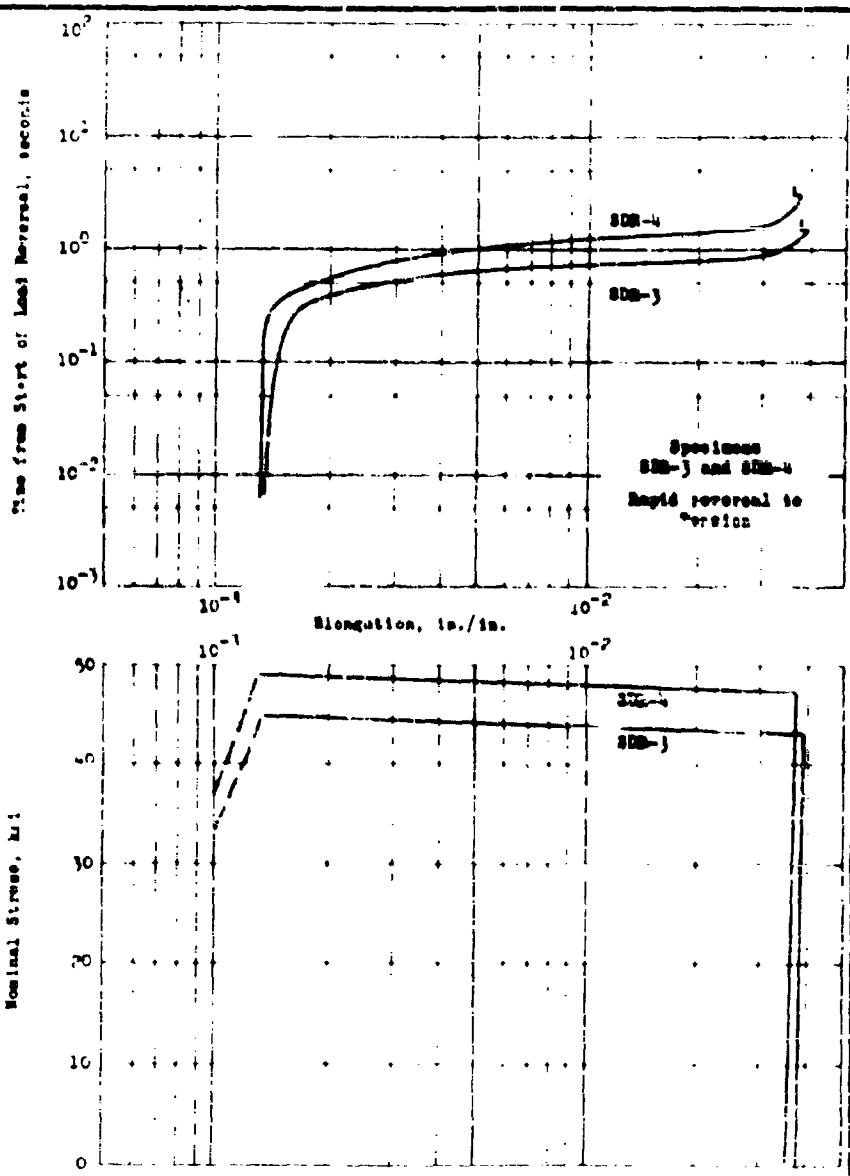


FIG. 30b STRESS - ELONGATION AND ELONGATION - TIME; RAPID REVERSAL FROM STATIC STRESS

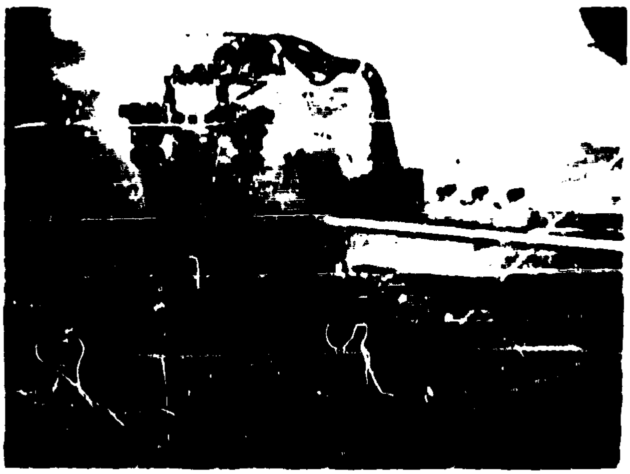


FIG. 51 OVERALL VIEW OF FLEXURAL TESTING EQUIPMENT

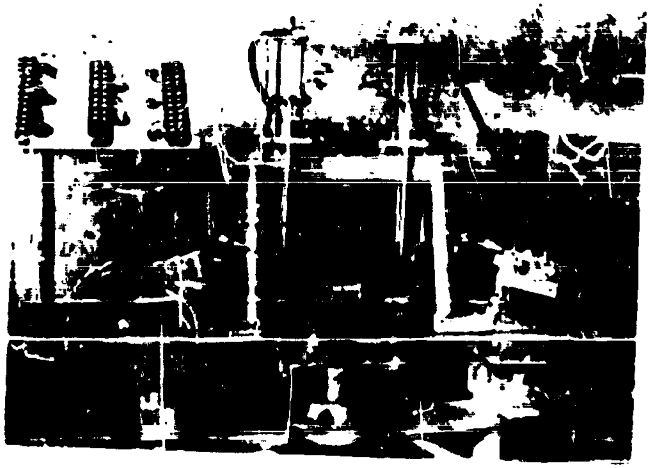


FIG. [illegible] ARRANGEMENT FOR TESTING SMALL BEAMS LOADED AT THE THIRD POINTS

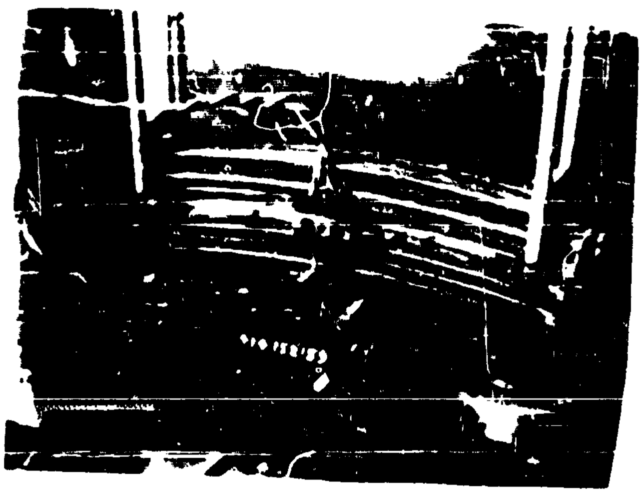


FIG. [illegible] [illegible] INSTRUMENTS

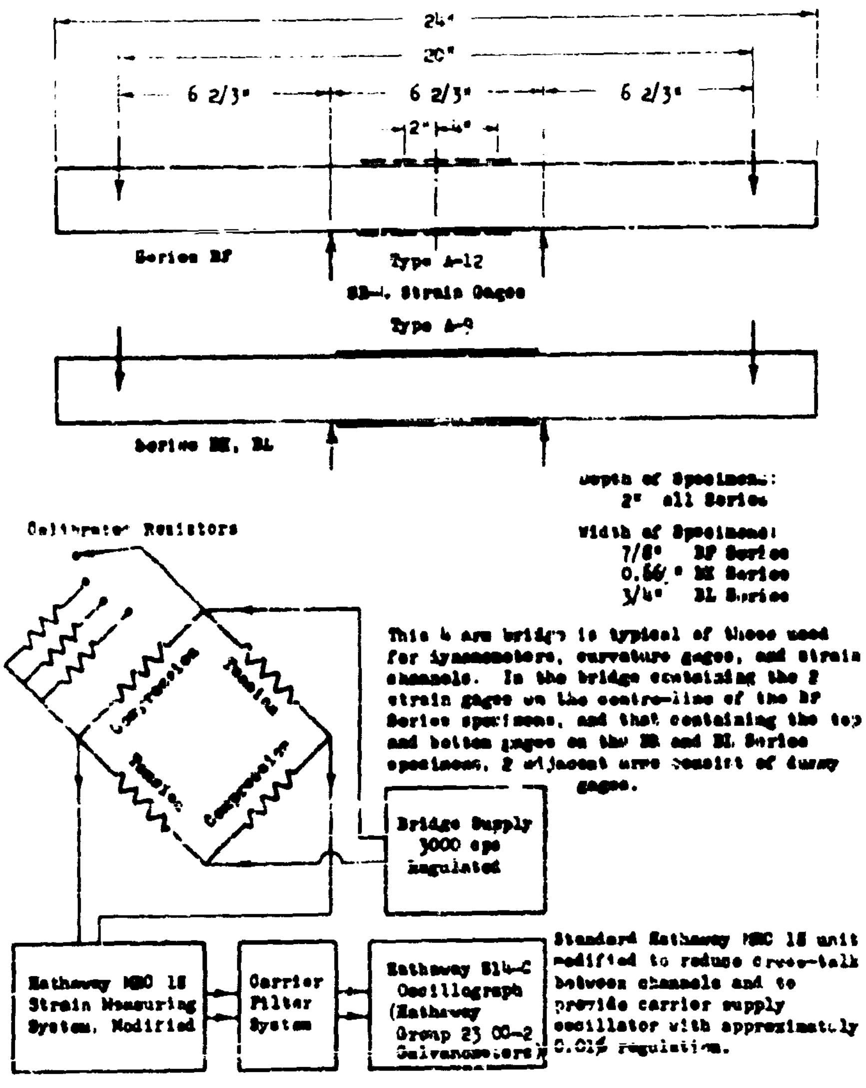
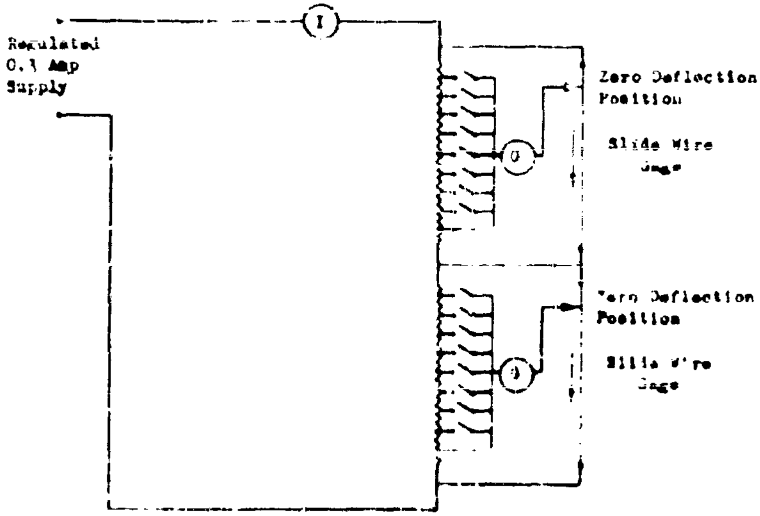


FIG. 34 INSTRUMENTATION AND DIMENSIONS OF FLEXURAL SPECIMENS



At zero deflection, bridge circuit had maximum unbalance. Both [illegible] bridge towards balance.

The switches were used to set the sensitivity of the bridge circuit. When used as calibration switches, they are roughly equivalent to [illegible] of deflection each.

For BF Series specimens, one additional similar bridge was used.

"G" represents a galvanometer.
"I" represents an ammeter.

FIG. 35 DEFLECTION GAGE CIRCUIT

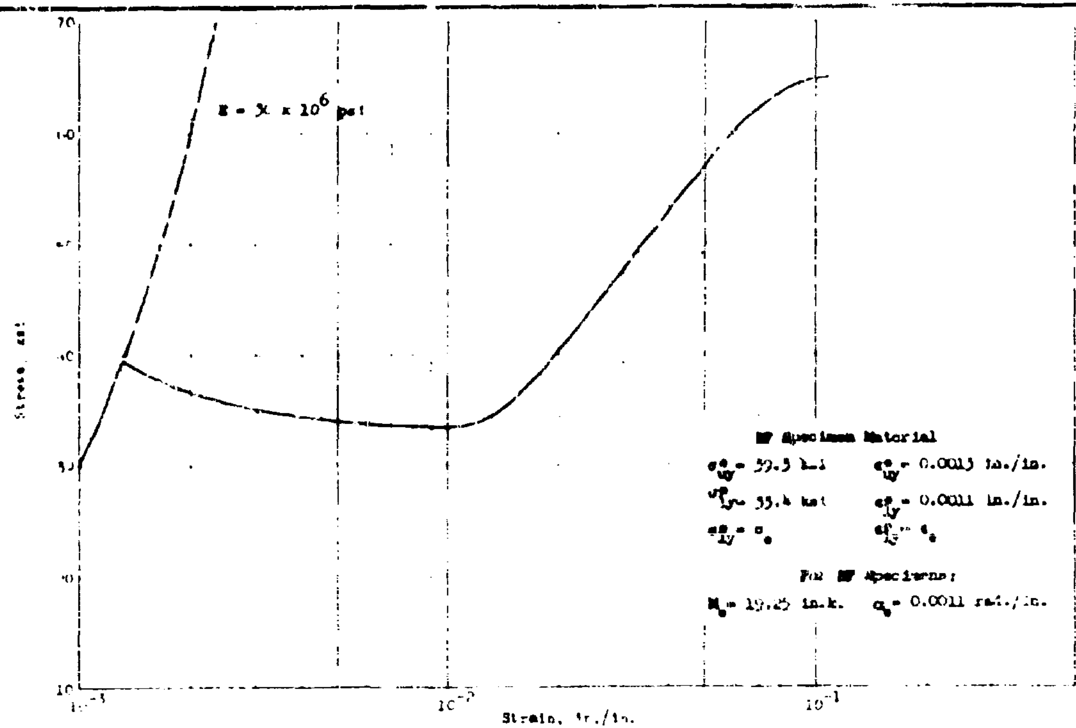
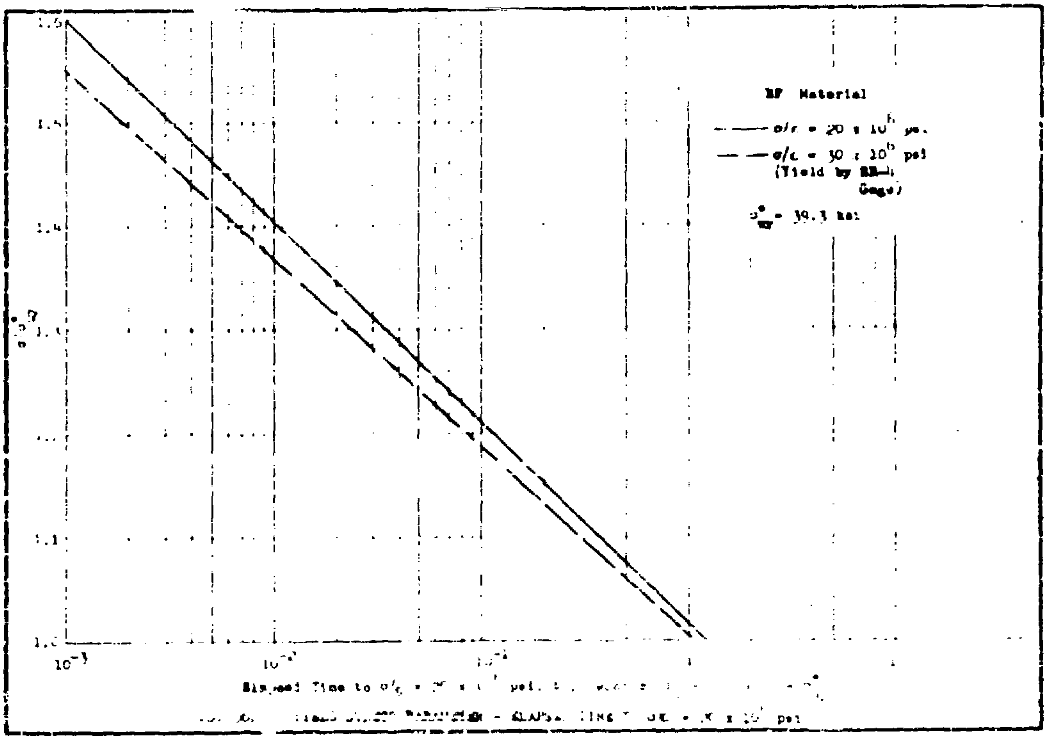


FIG 4.4 STRESS – STRAIN


HF Material
σ/ε = 20 x 10^6 psi
σ/ε = 30 x 10^6 psi
(Yield by SR-4 Gage)
= 39.3 ksi
1.5
1.4
1.1
1.0
10^-3
10^-2
10^-1
1
Elapsed Time to

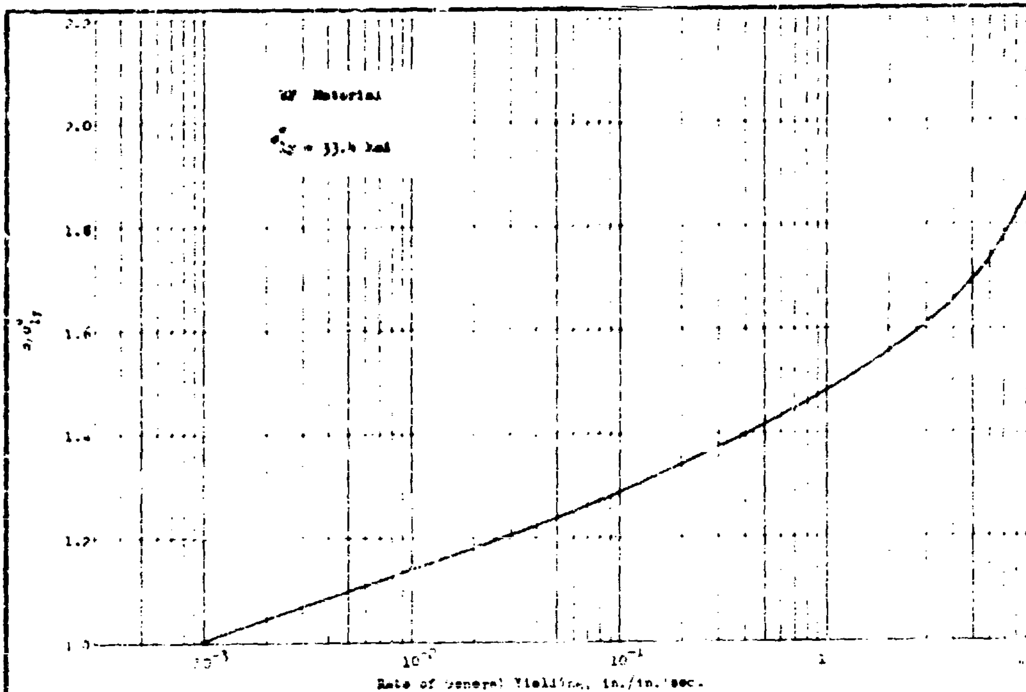


FIG. 36c YIELD STRESS PARAMETER – RATE OF YIELDING AT CONSTANT STRESS

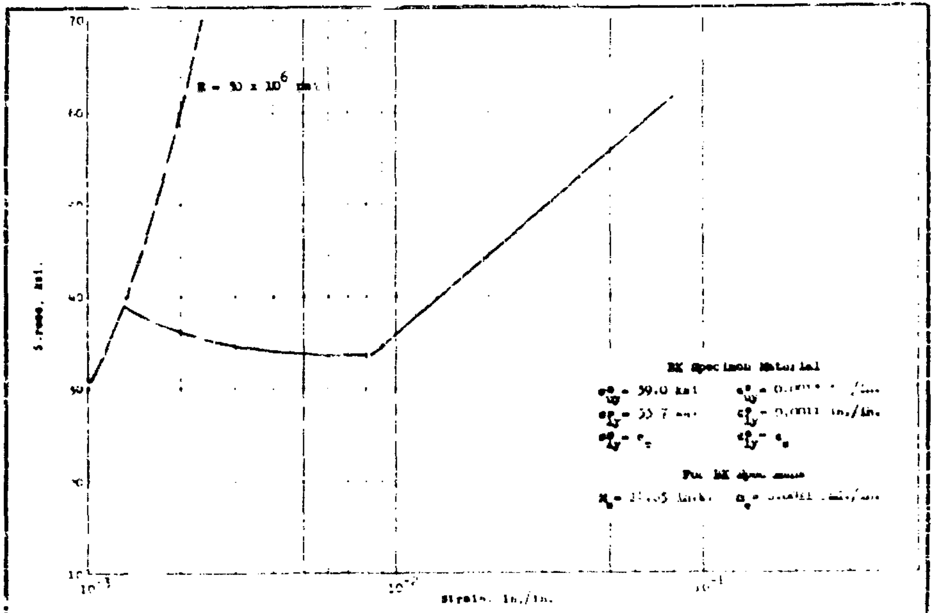


FIG. 9cd STRESS STRAIN

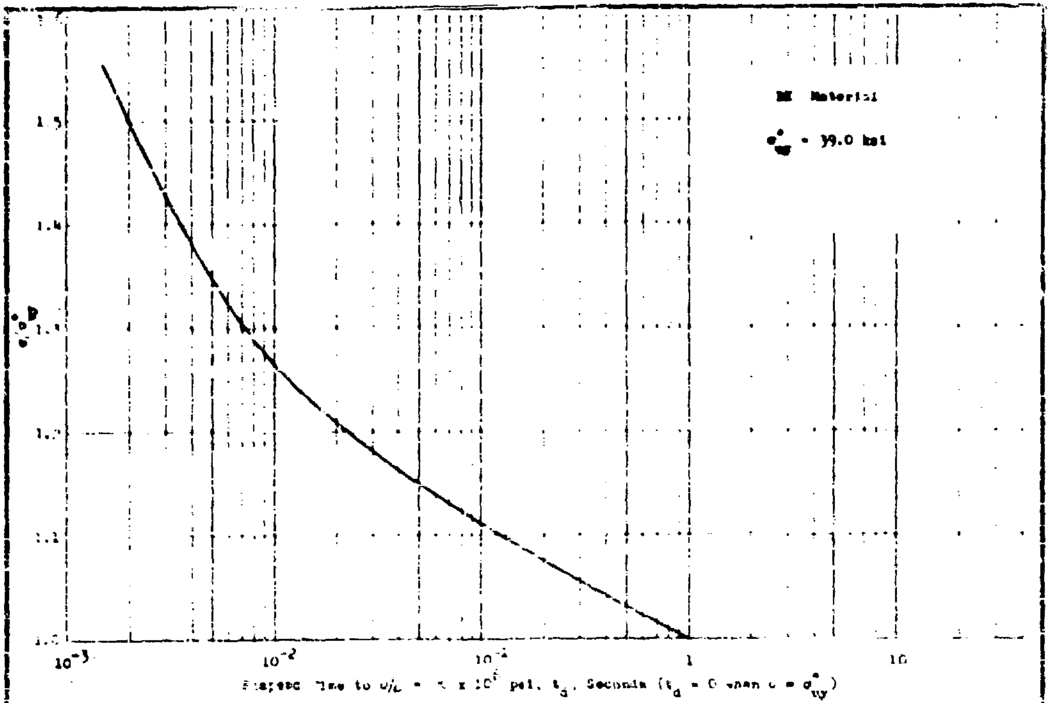
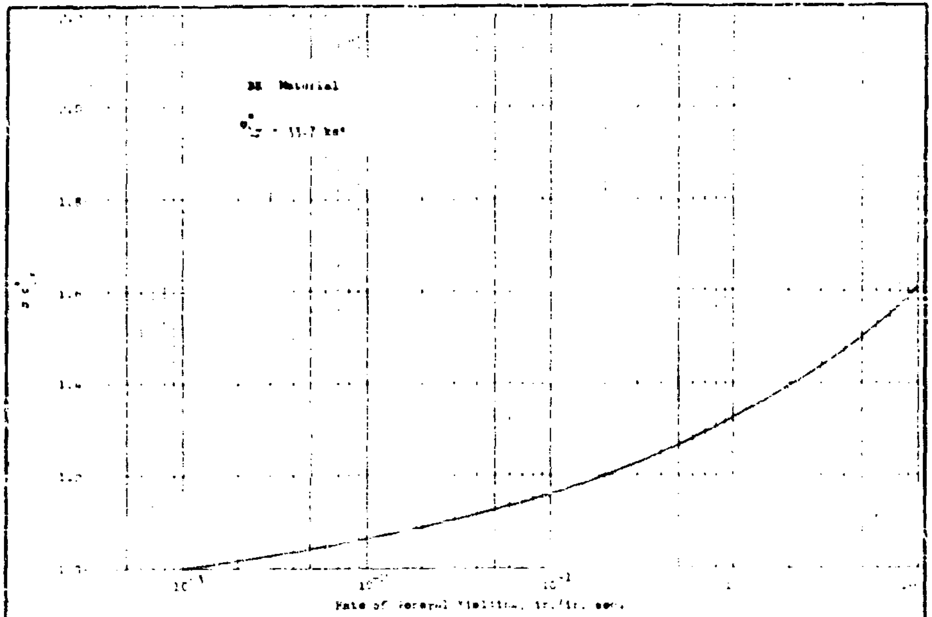


FIG. 39e YIELD STRESS PARAMETER - ELAPSED TIME TO σ/ε = 20 x 10⁶ psi



STRESS PARAMETER - RATE OF YIELDING AT CONSTANT

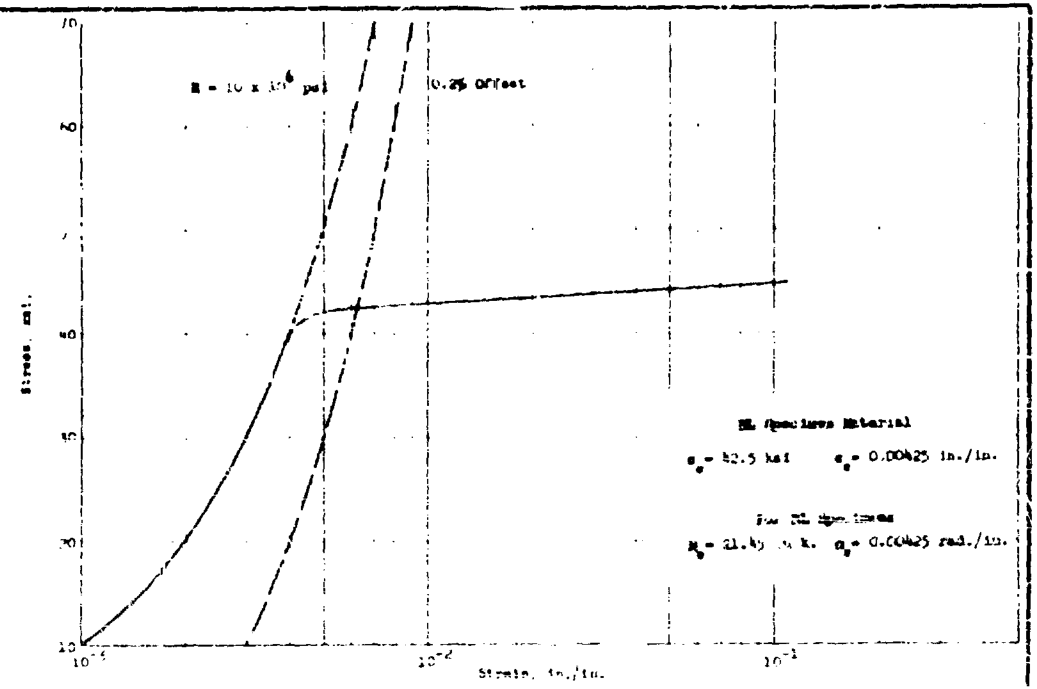
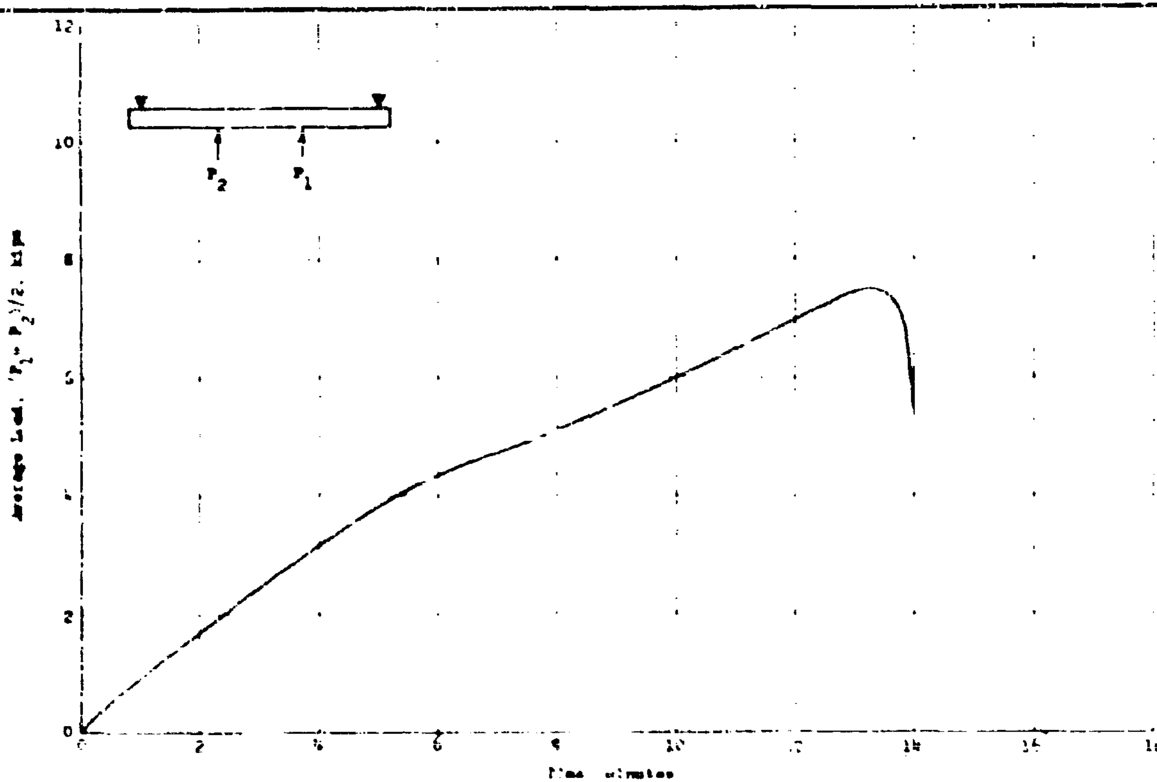


FIG. 36g STRESS - STRAIN



[illegible] LOAD - TIME, SPECIMEN [illegible]

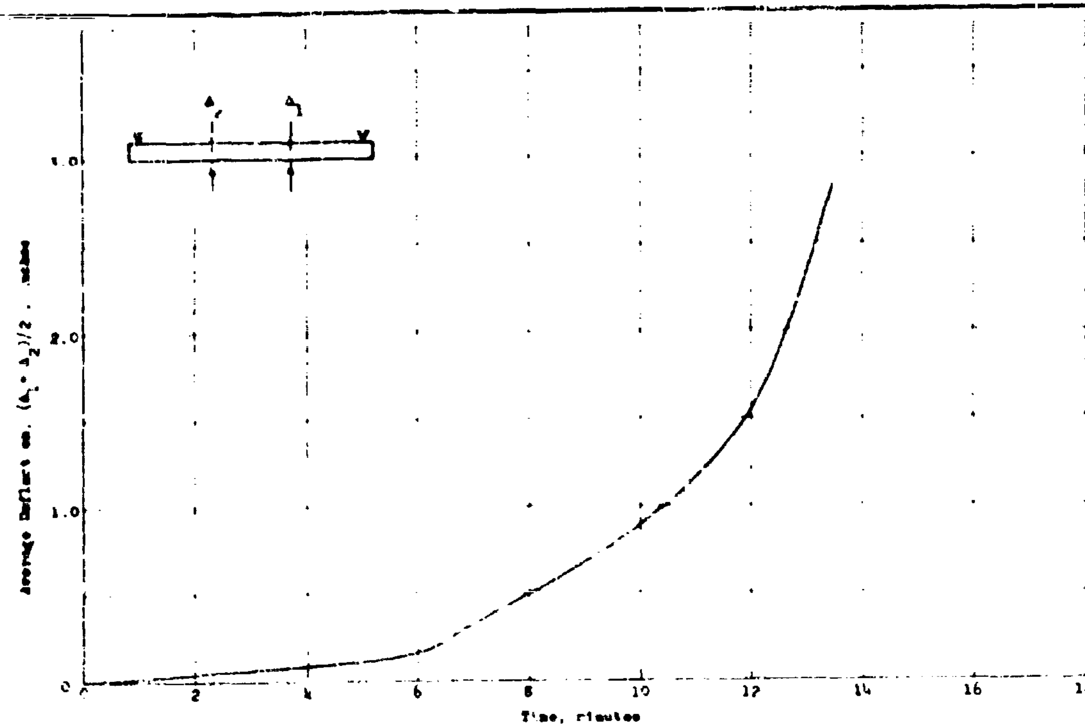


FIG. 37? DEFLECTION - TIME, SPECIMEN BP-1

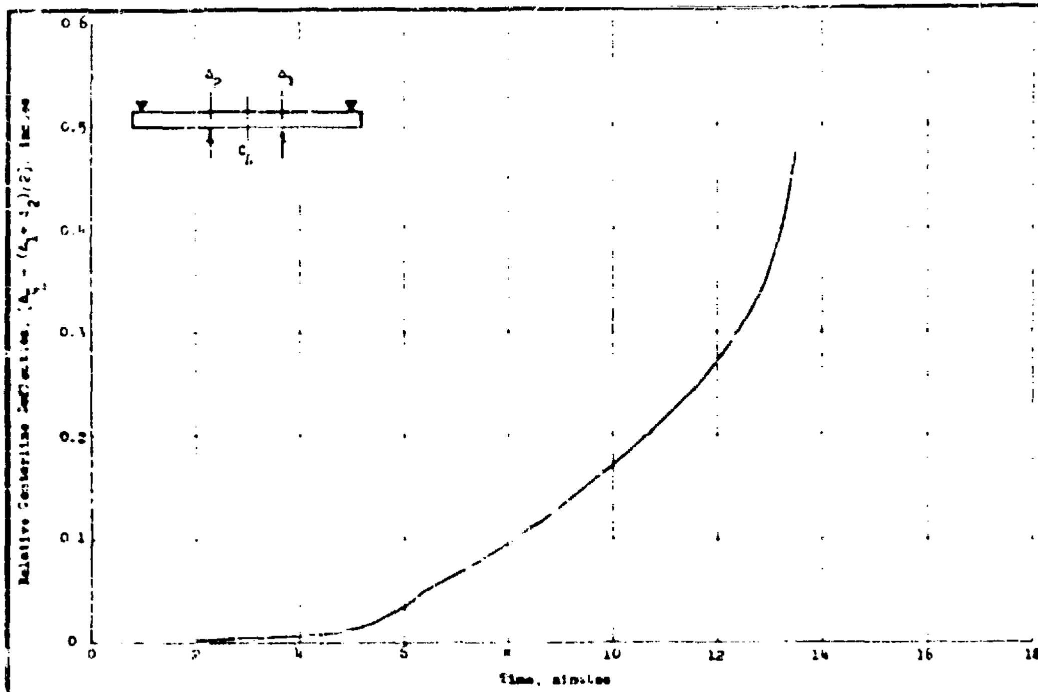


FIG. 57c RELATIVE CENTERLINE DEFLECTION – TIME, SPECIMEN B-

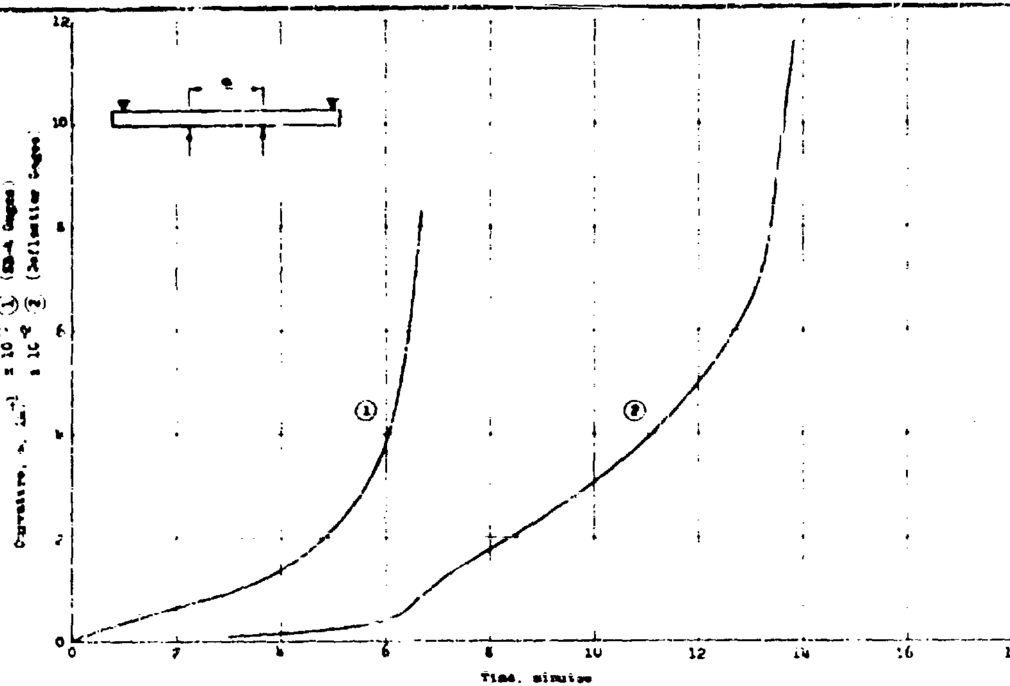


FIG. 57d CURVATURE - TIME, SPECIMEN NO. 1

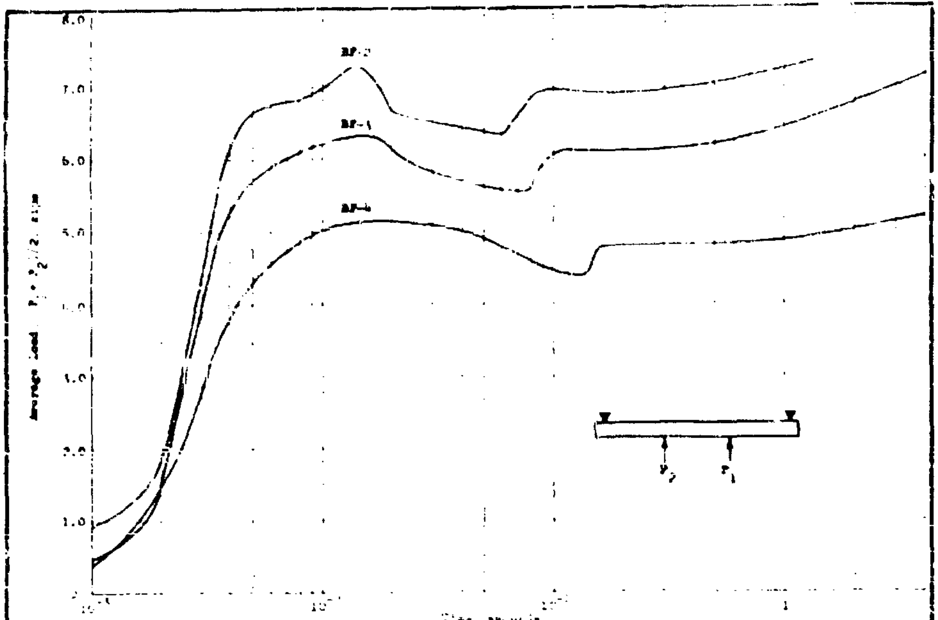
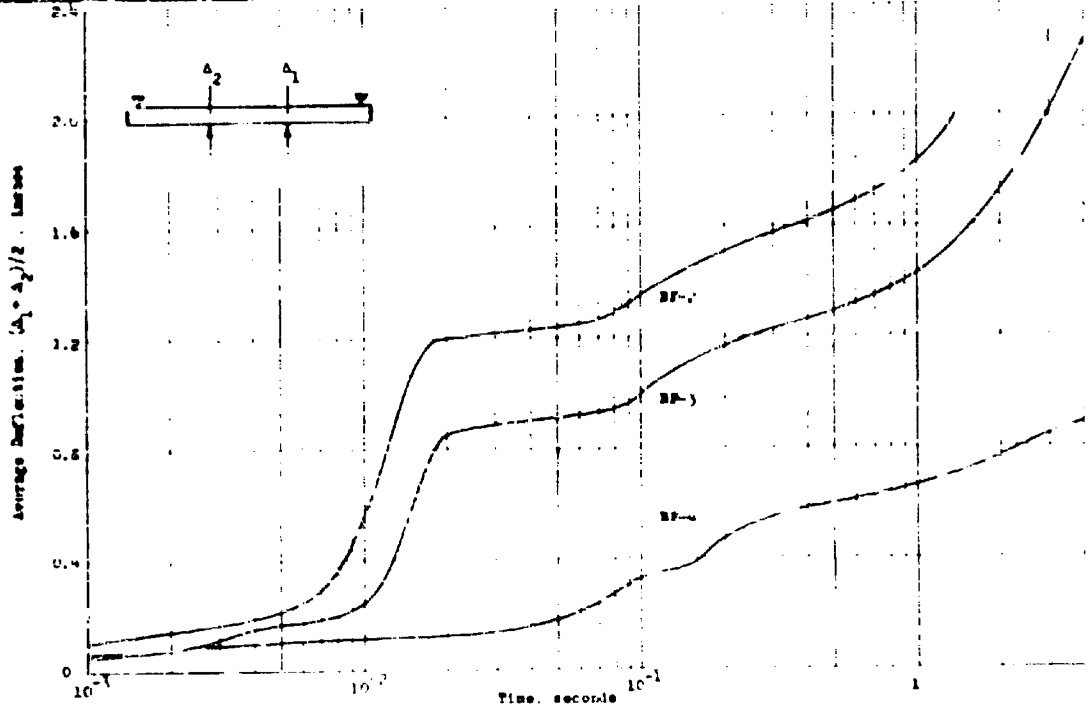


FIG. 17a LOAD - TIME, SPECIMENS BF-2, BF-3, BF-4.



DEFLECTION - TIME, SPECIMENS BP-2, BP-3, BP-4.

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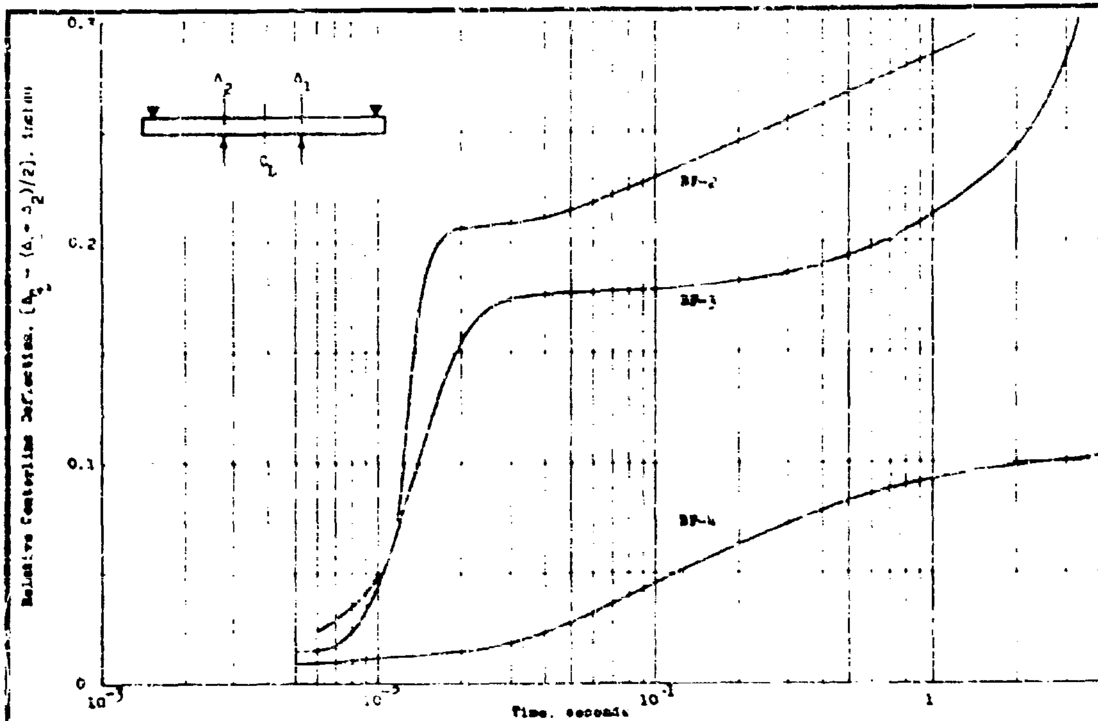


FIG. 5.8 RELATIVE CENTERLINE DEFLECTION vs TIME, SPECIMENS BP-2, BP-3, BP-4.

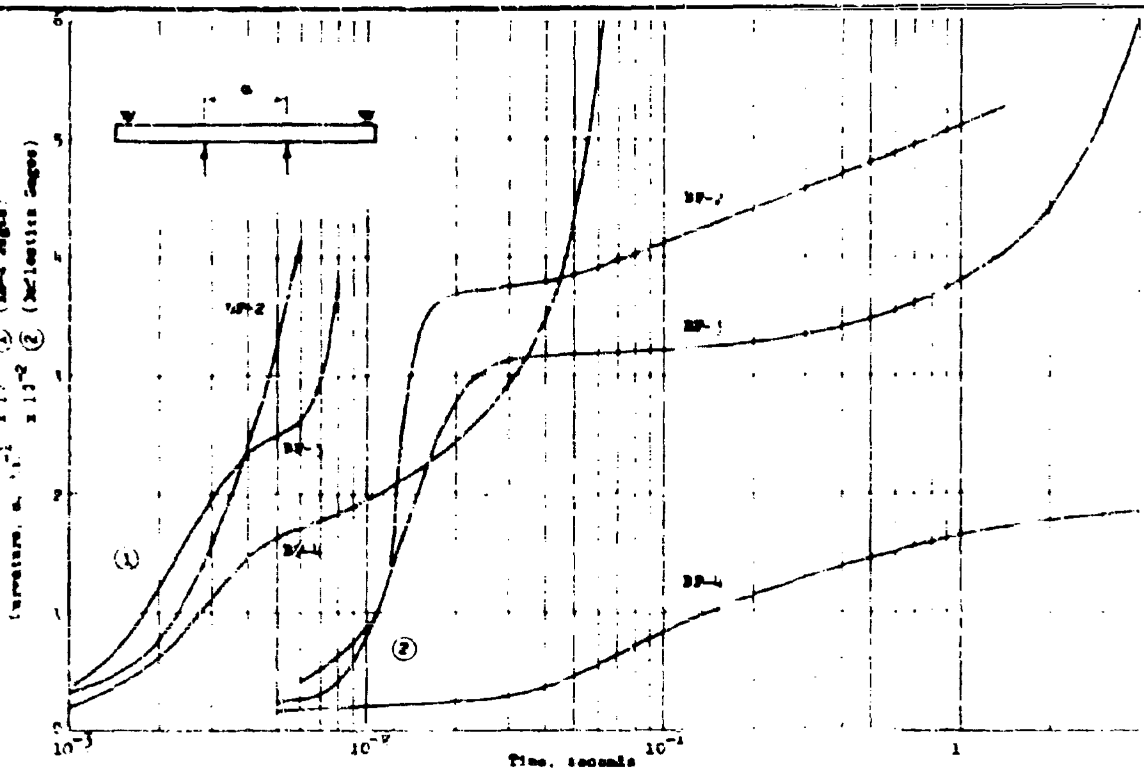


FIG. 5/5 CURVATURE – TIME, SPECIMENS BP-2, BP 3, BP-4.

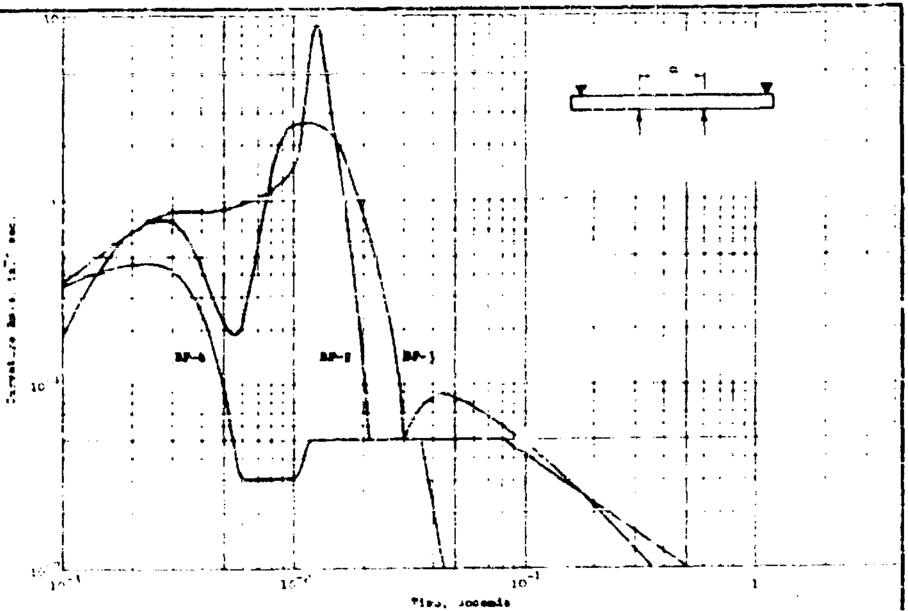


FIG. 57. CURVATURE RATE VS. TIME, SPECIMENS BP-2, BP-3, BP-4

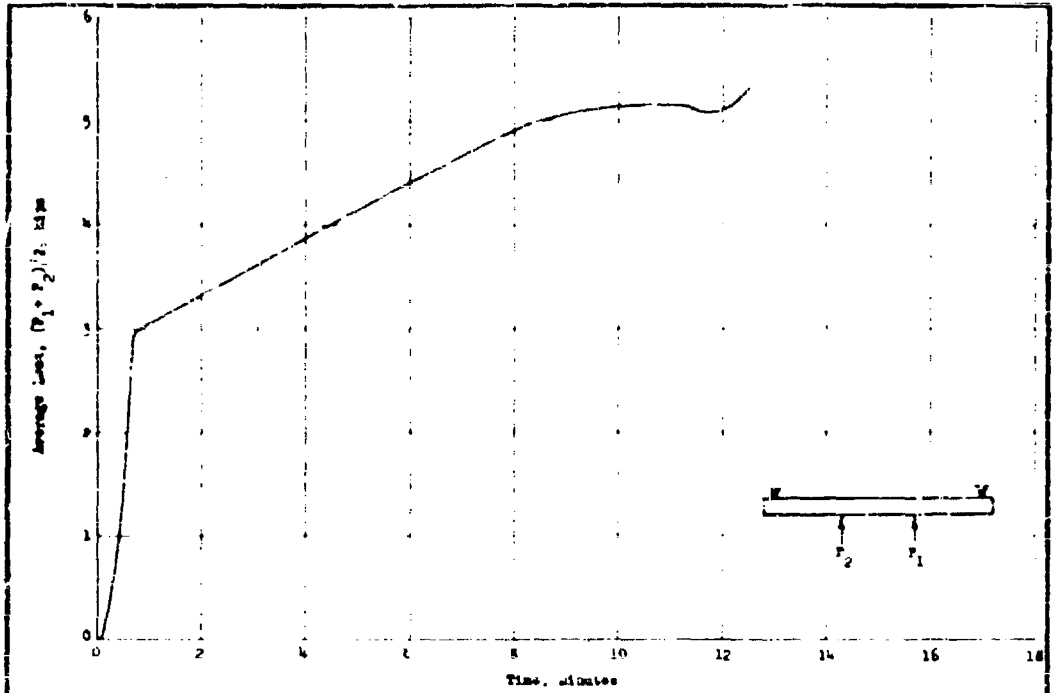


Fig. [illegible] LOAD - TIME, SPECIMEN BE-1

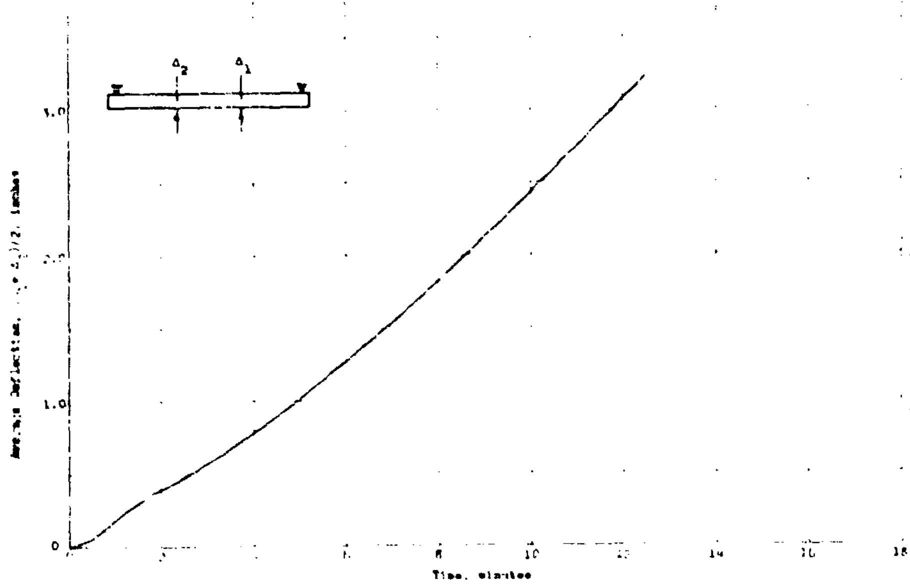


FIG. [illegible] DEFLECTION - TIME, SPECIMEN BK-1

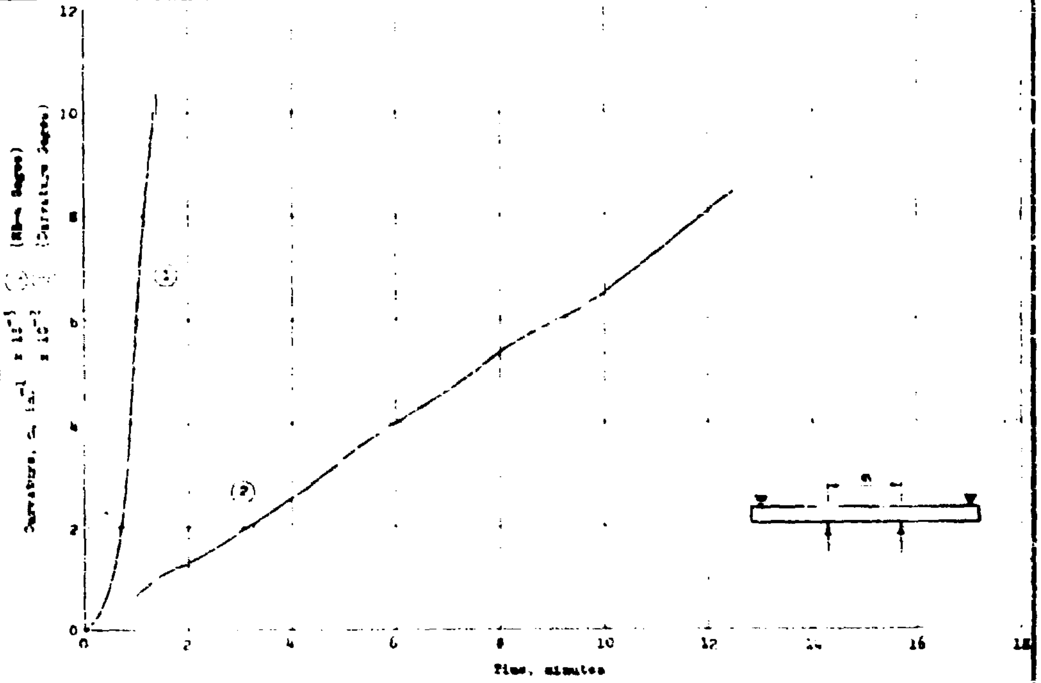


FIG. 30 CURVATURE - TIME, SPECIMEN BK-1

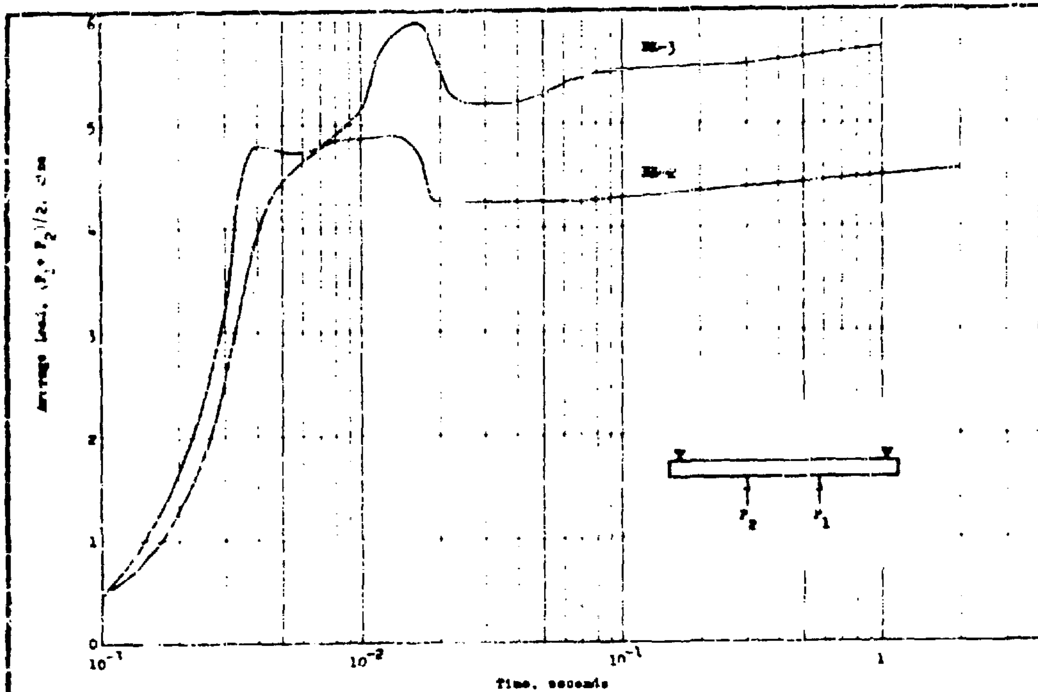


FIG. F-1 LOAD - TIME, SPECIMENS

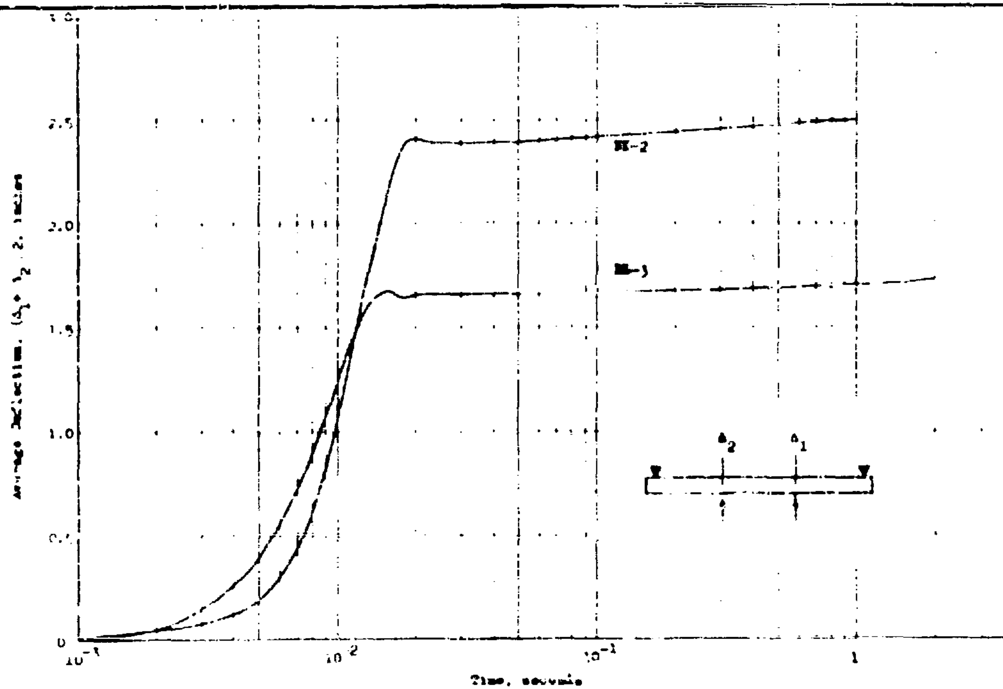


FIG. [illegible] DEFLECTION - TIME, SPECIMENS BE-2, BE-3

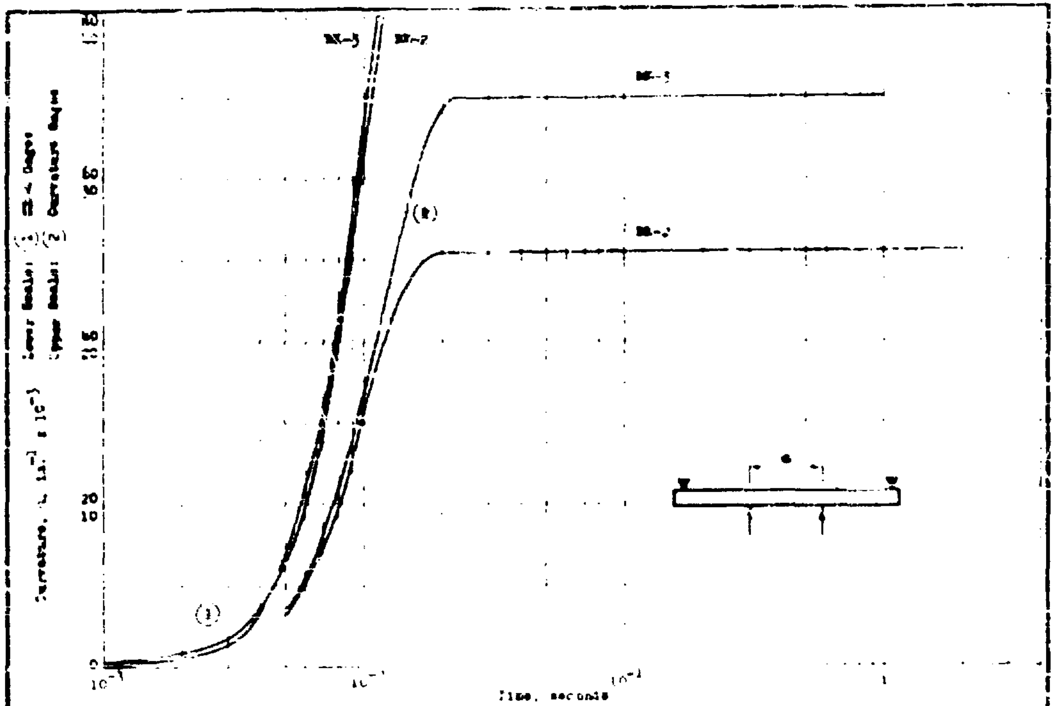


FIG. 35f CURVATURE – TIME, SPECIMENS BR-2, BR-3

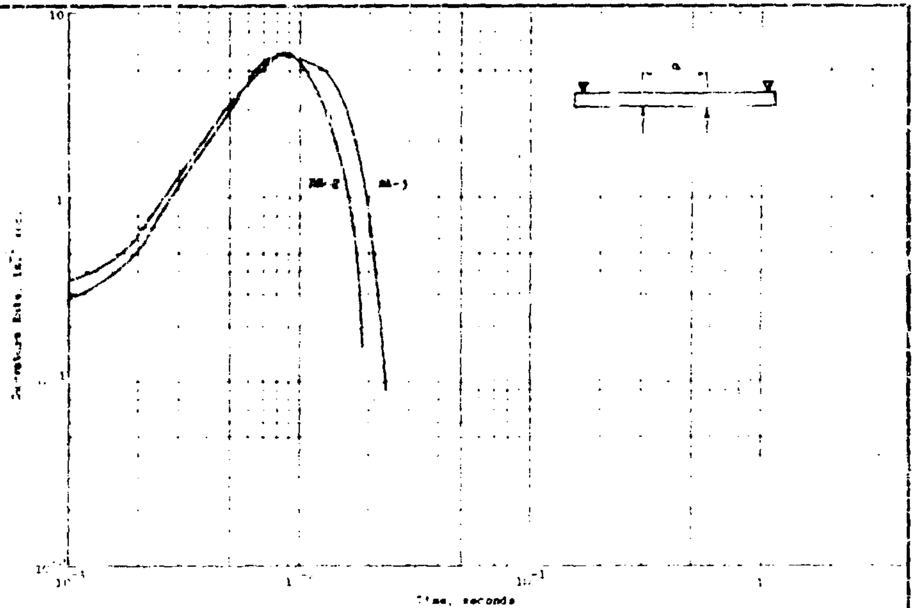


FIG. [illegible] CURVATURE RATE - TIME, SPECIMENS BE-2, BE-3

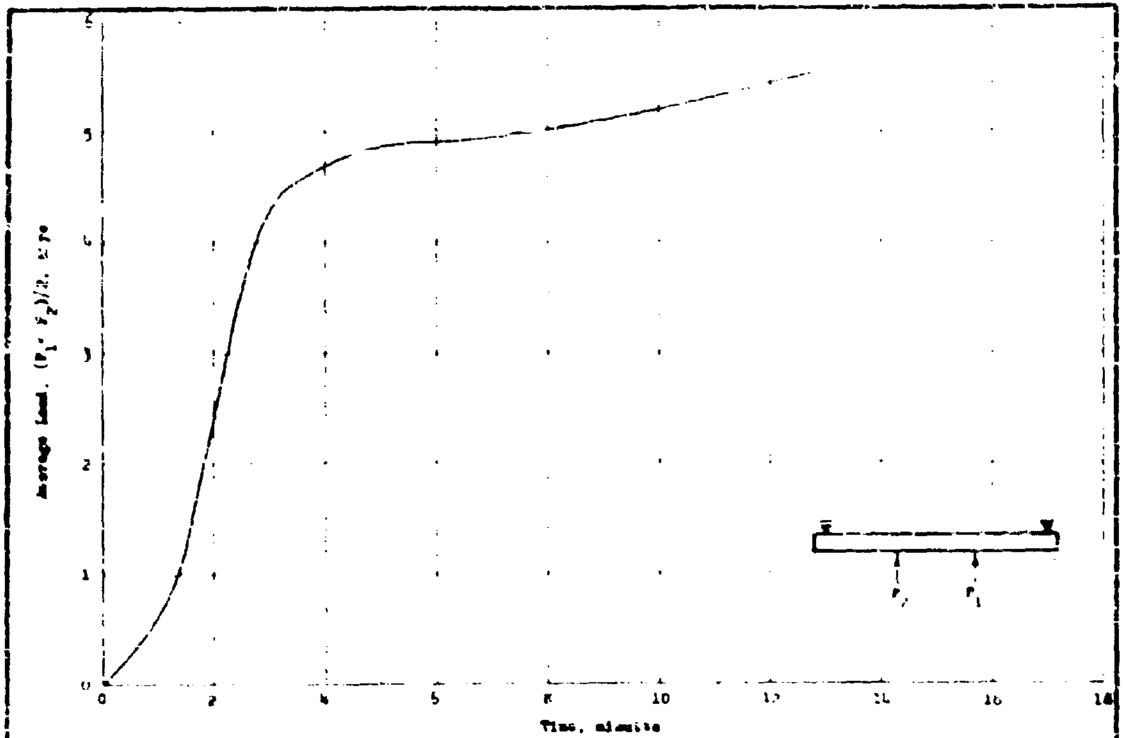


FIG. 50a LOAD - TIME, SPECIMEN BL-1

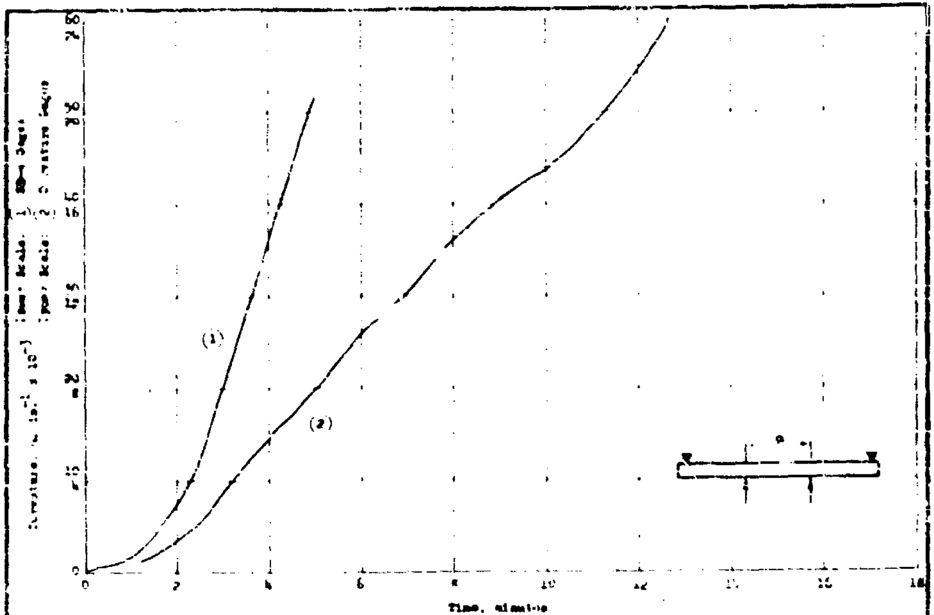


FIG. [illegible] CURVATURE - TIME, SPECIMEN B1-1

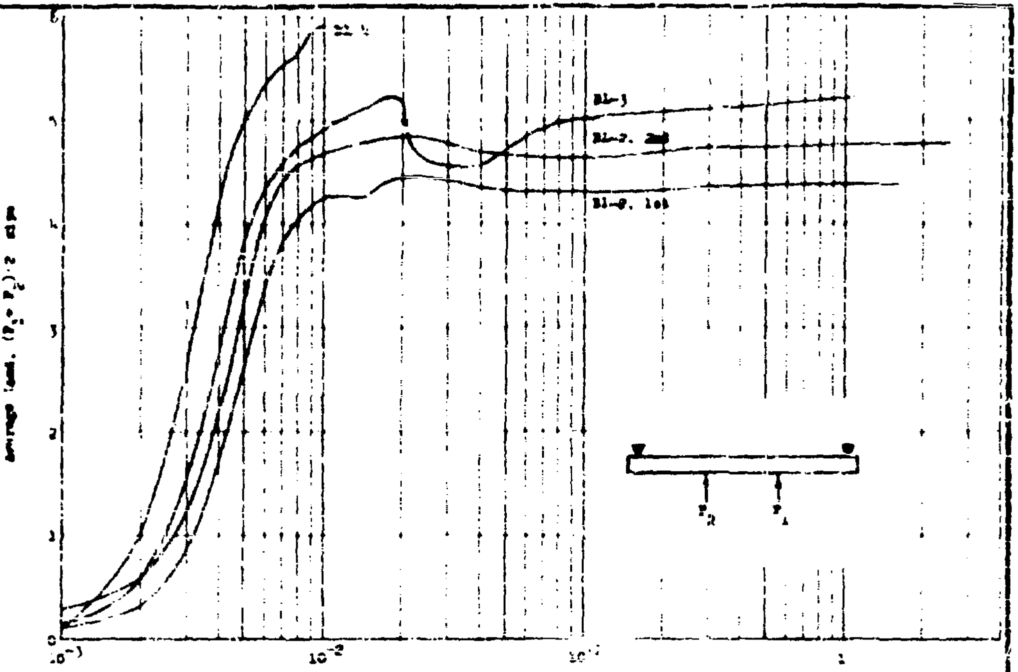


FIG. 394 LOAD - TIME, SPECIMENS BL-2, BL-3, BL-4

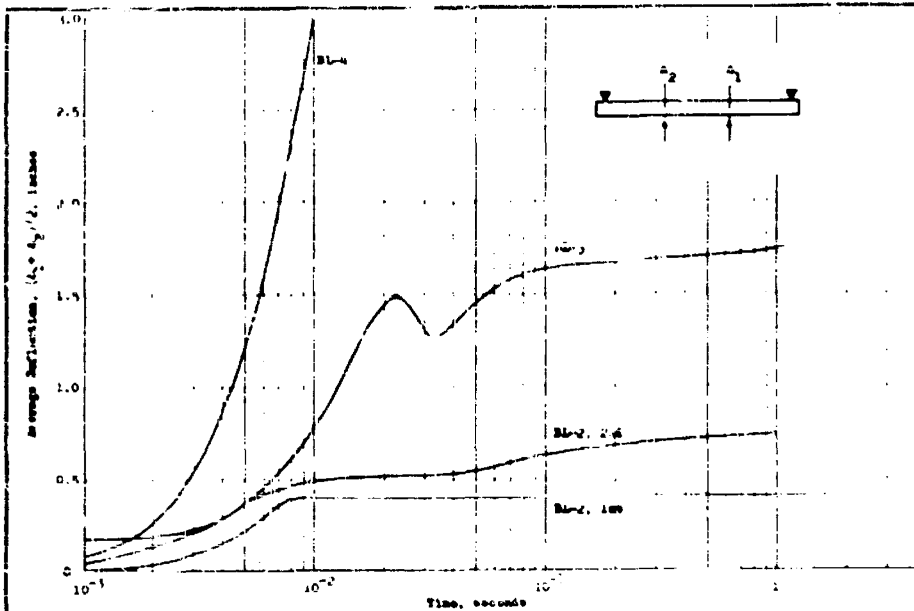


FIG. 59a DEFLECTION - TIME, SPECIMENS BL-2, BL-3, BL-4

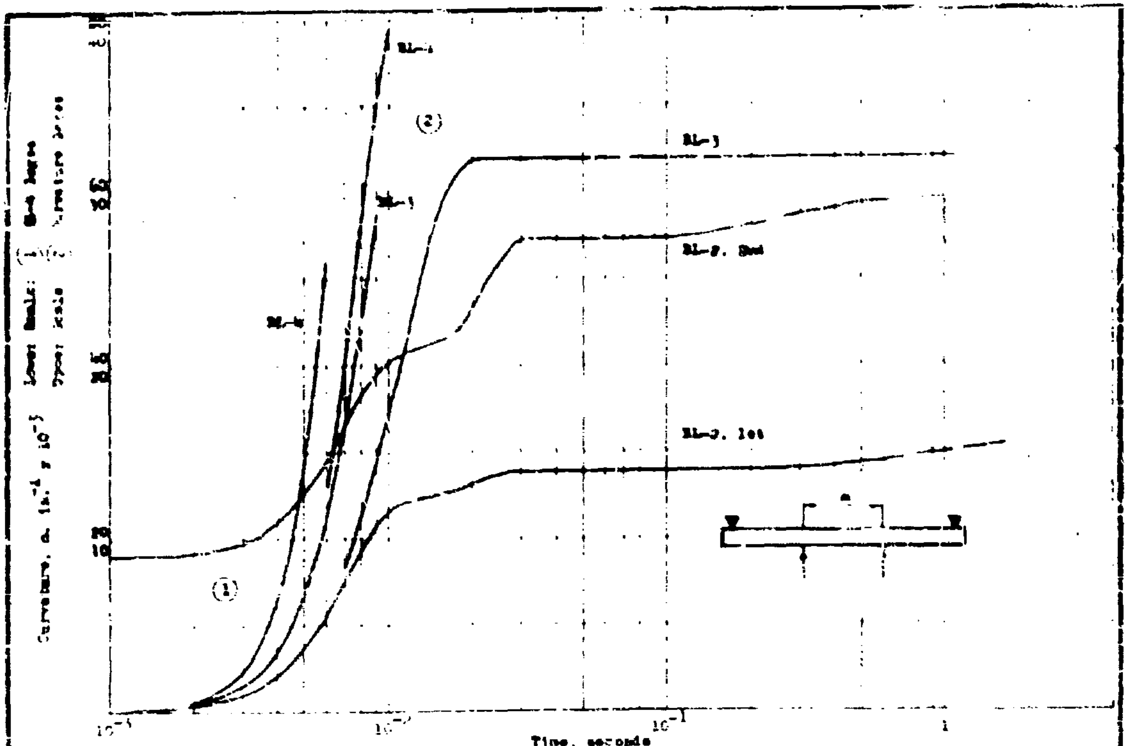


FIG. 59C CURVATURE - TIME, SPECIMENS BL-2 BL-3, BL-4

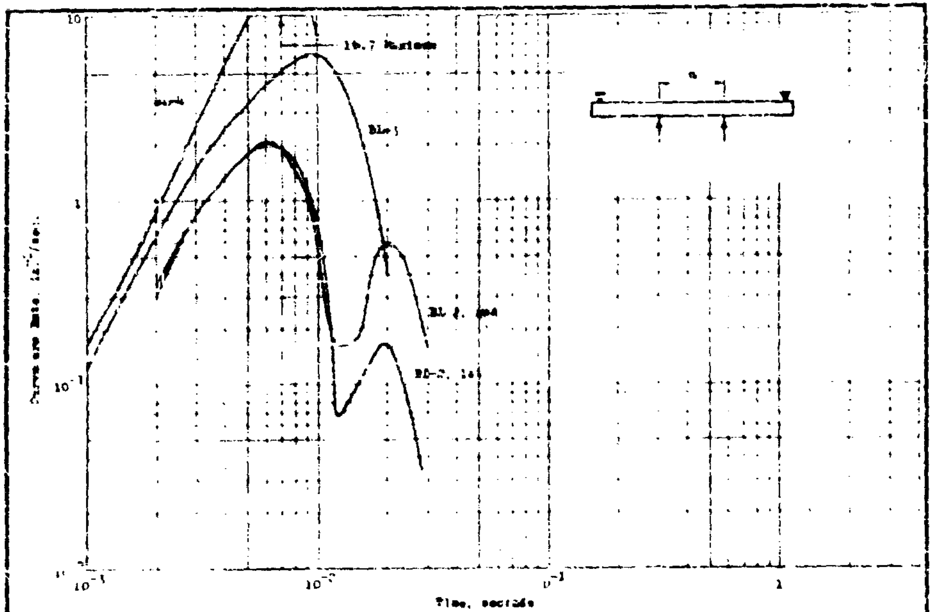


FIG. 39g CURVATURE RATE - TIME, SPECIMENS BL-2, BL-3, BL-4

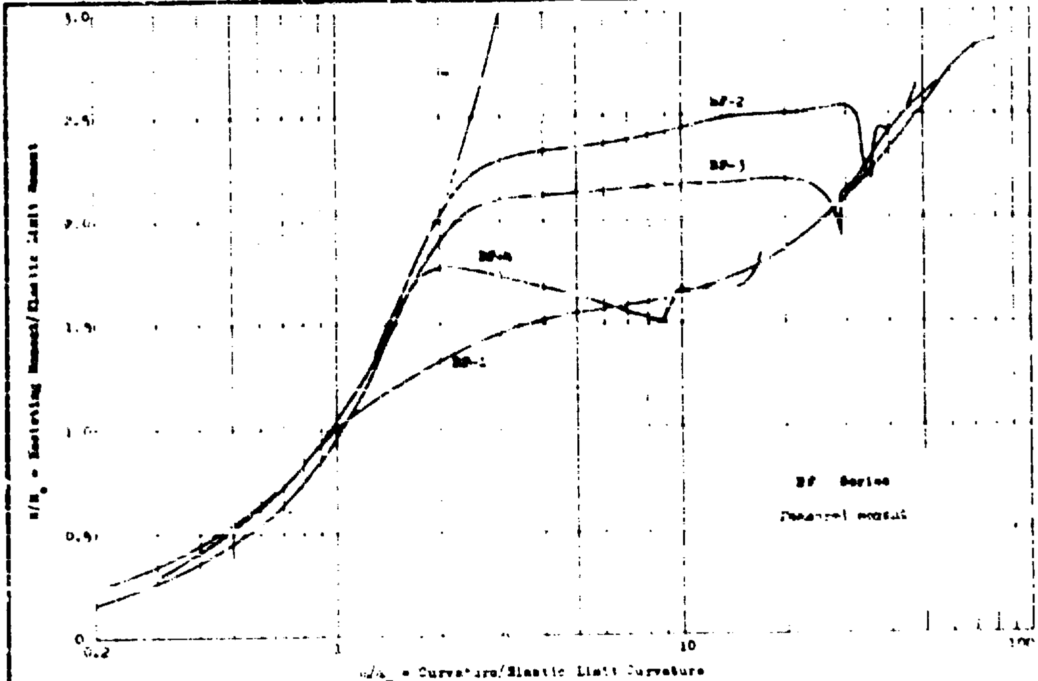


Fig. RESISTING MOMENT - CURVATURE

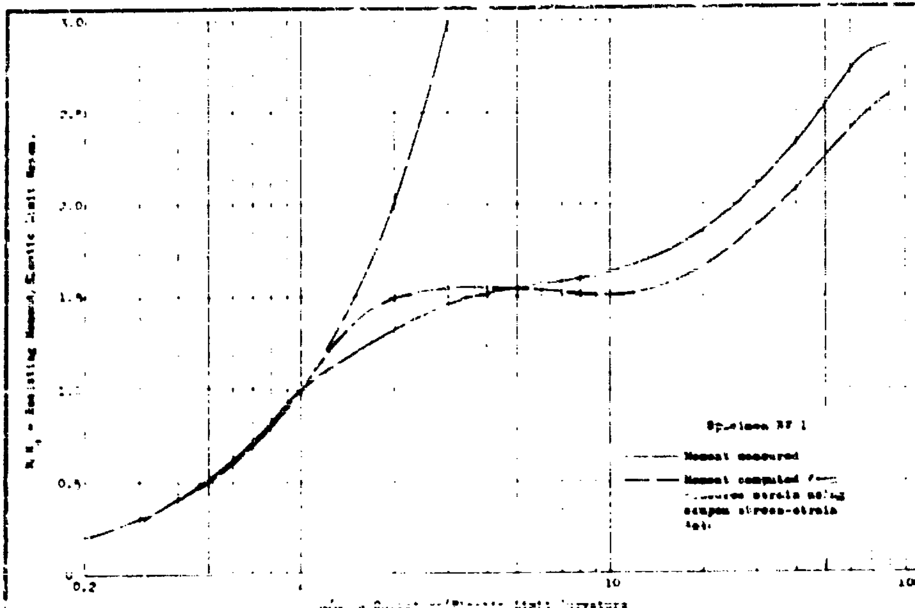
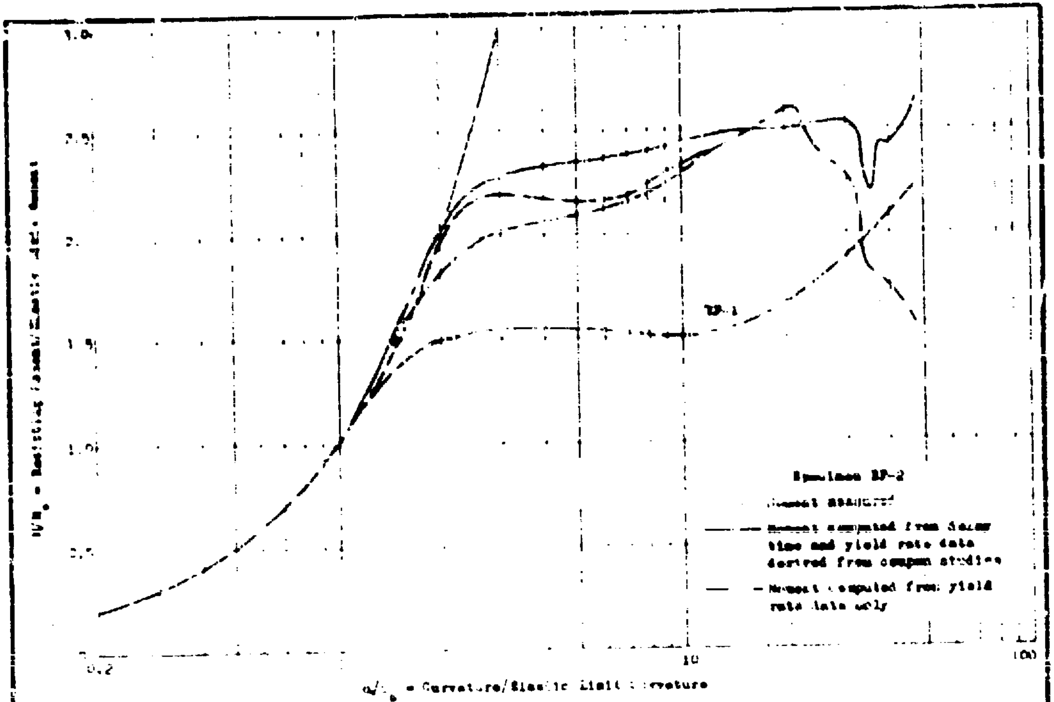
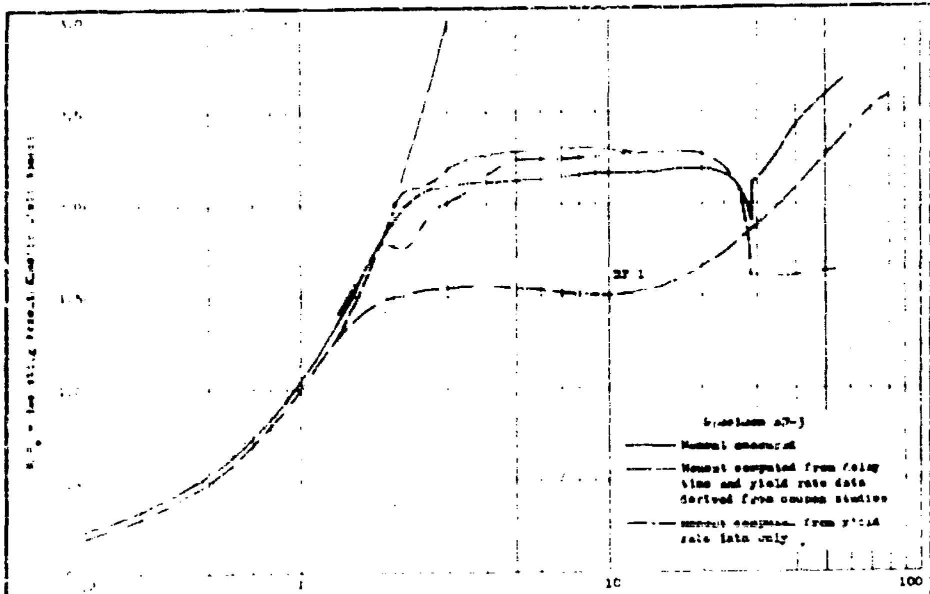


FIG. 40L RESISTING MOMENT - CURVATURE



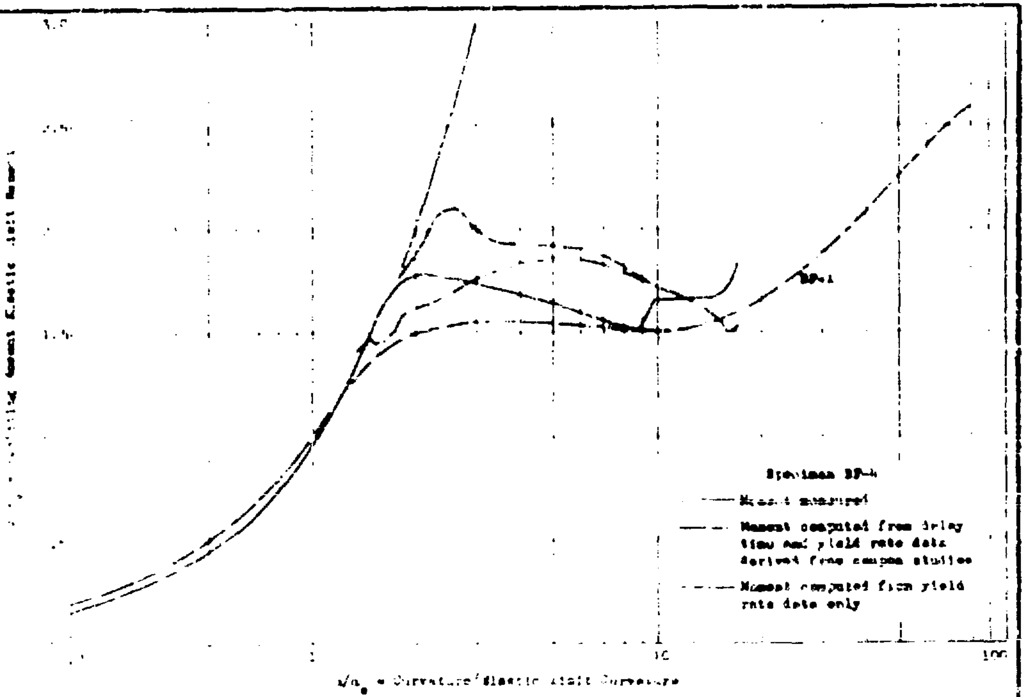
ϕ/ϕ_e = Curvature/Elastic Limit Curvature

FIG. 40c RESISTING MOMENT - CURVATURE



ϕ/ϕ_e = Curvature/Elastic Limit Curvature

FIG. RESISTING MOMENT - CURVATURE



RESISTING MOMENT - CURVATURE

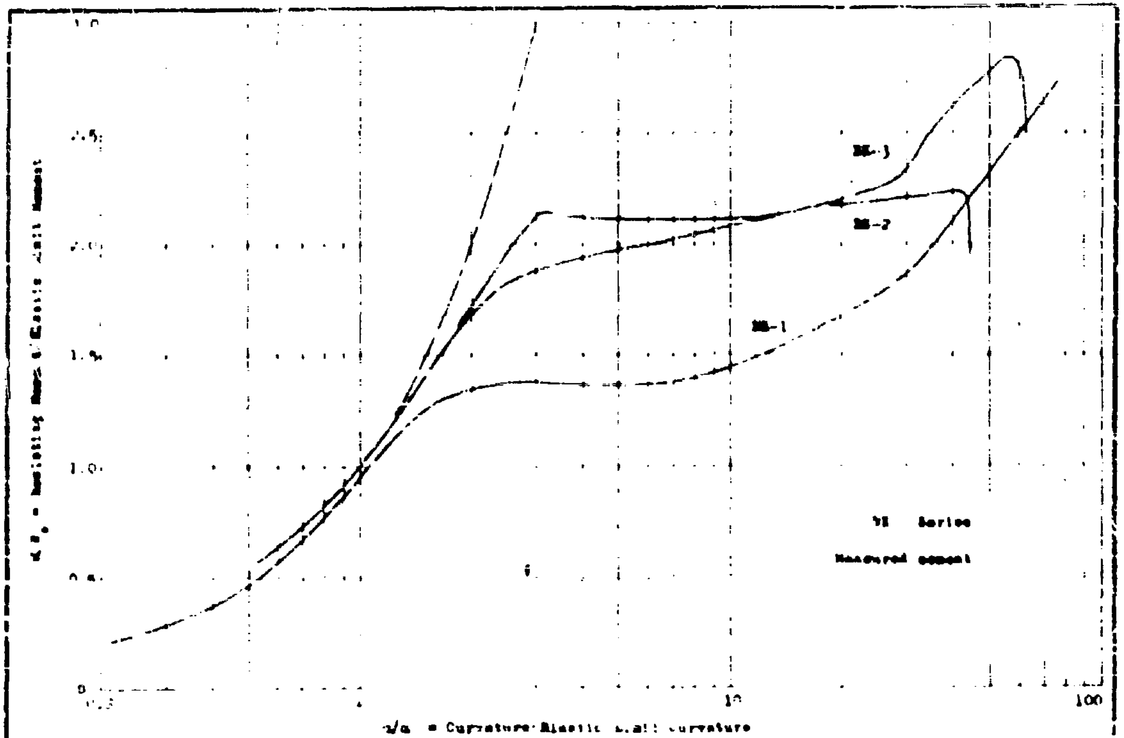
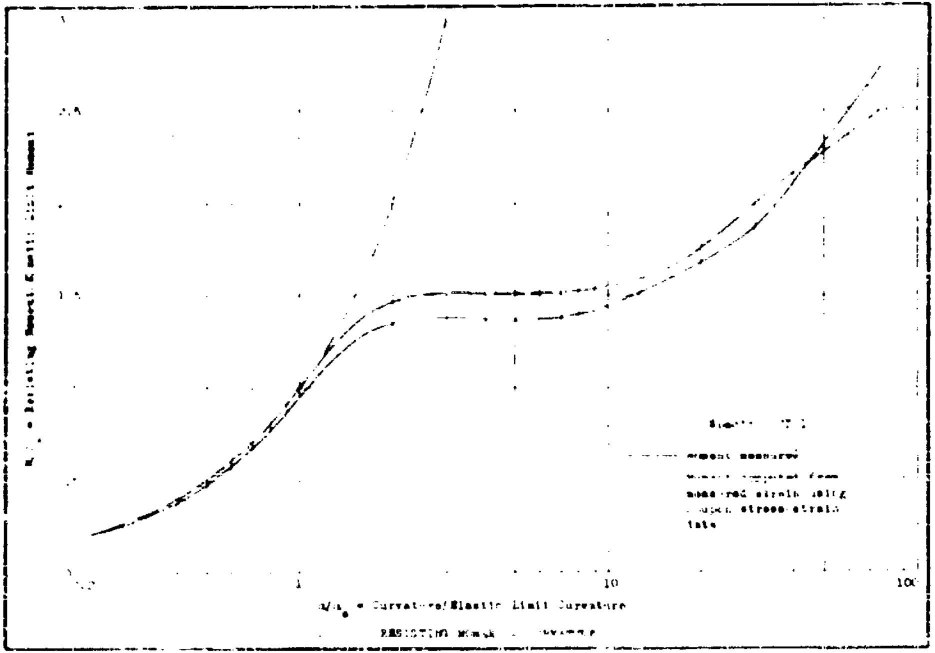
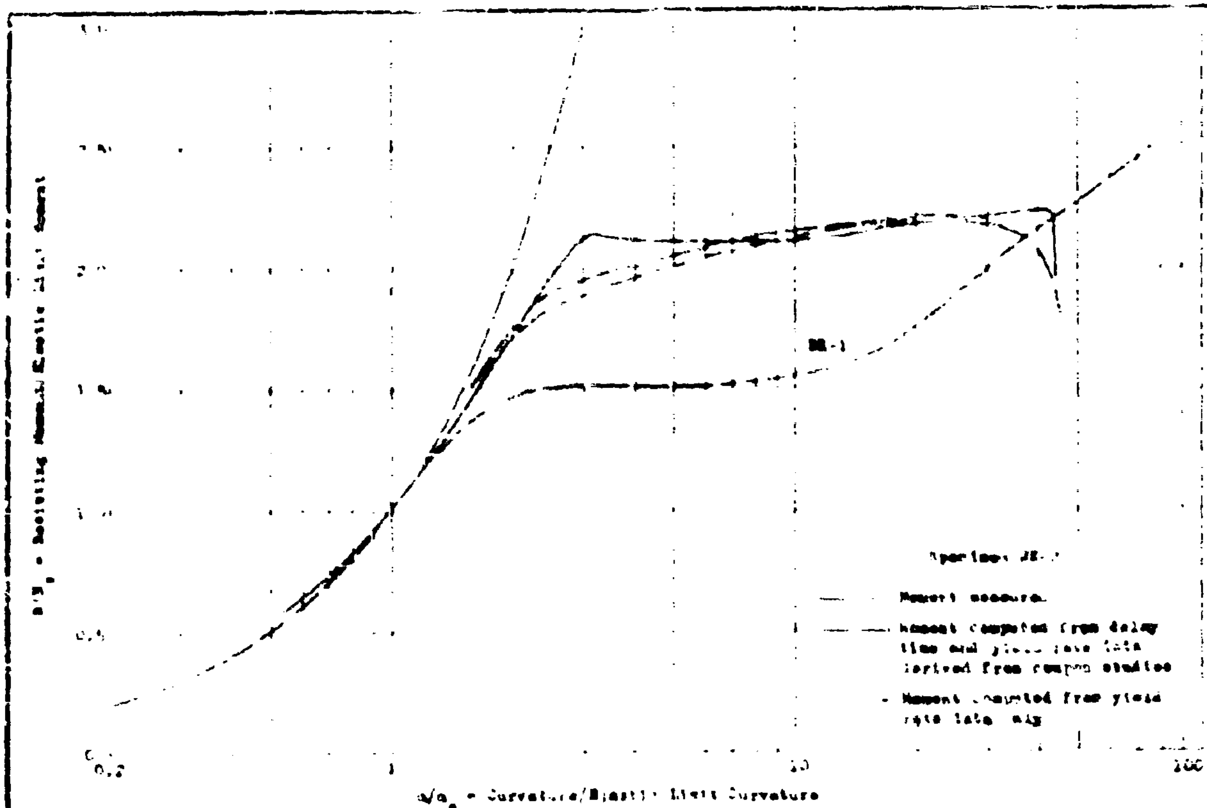
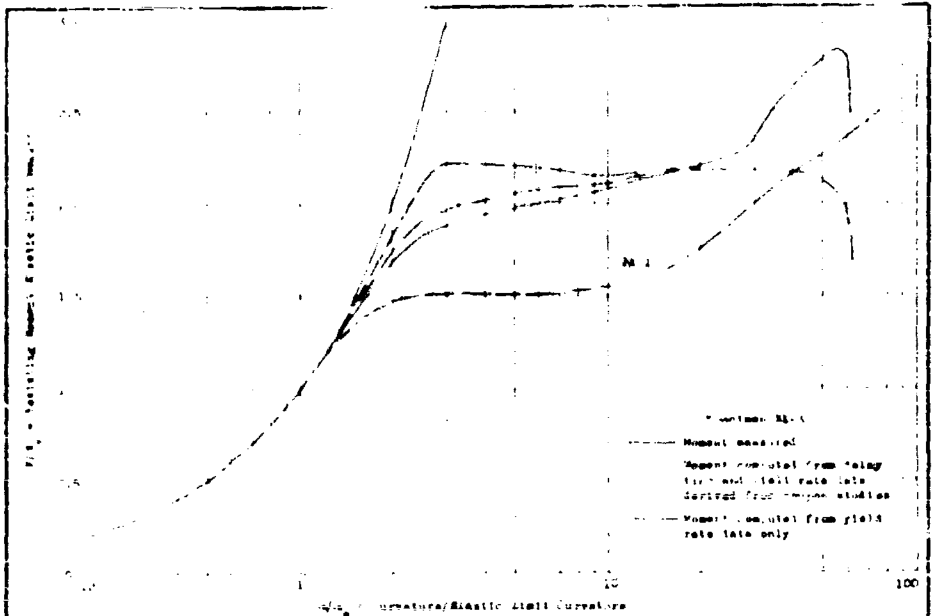


FIG. 41a RESISTING MOMENT - CURVATURE

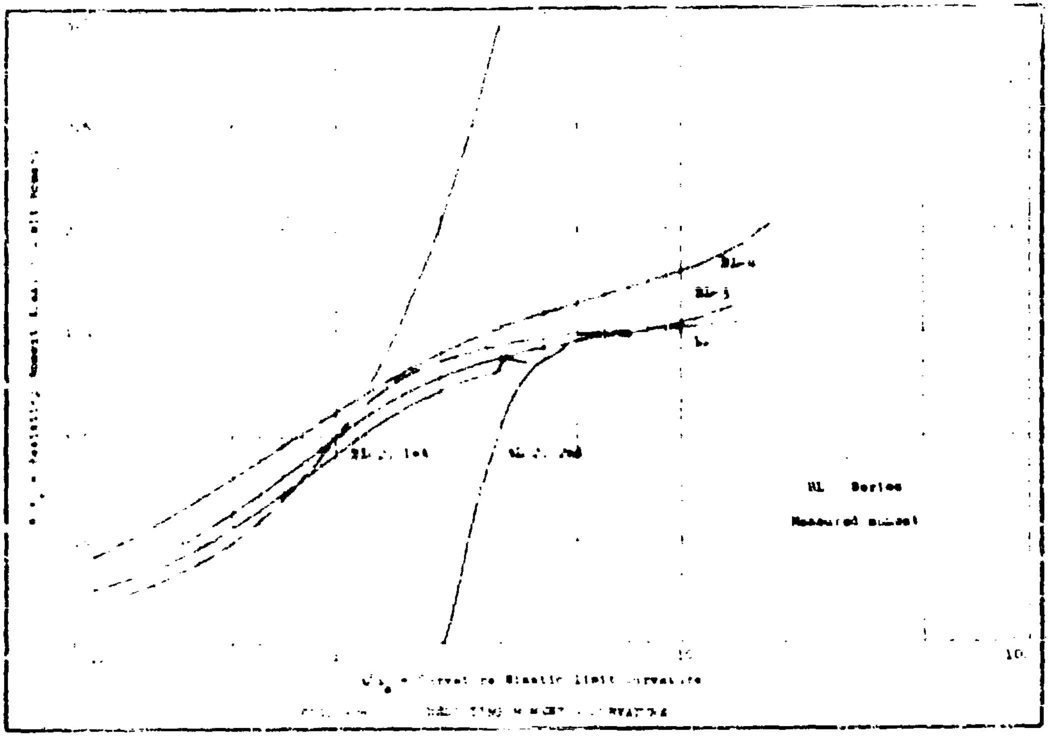

1
10
100
moment measured
Curvature/Elastic Limit Curvature



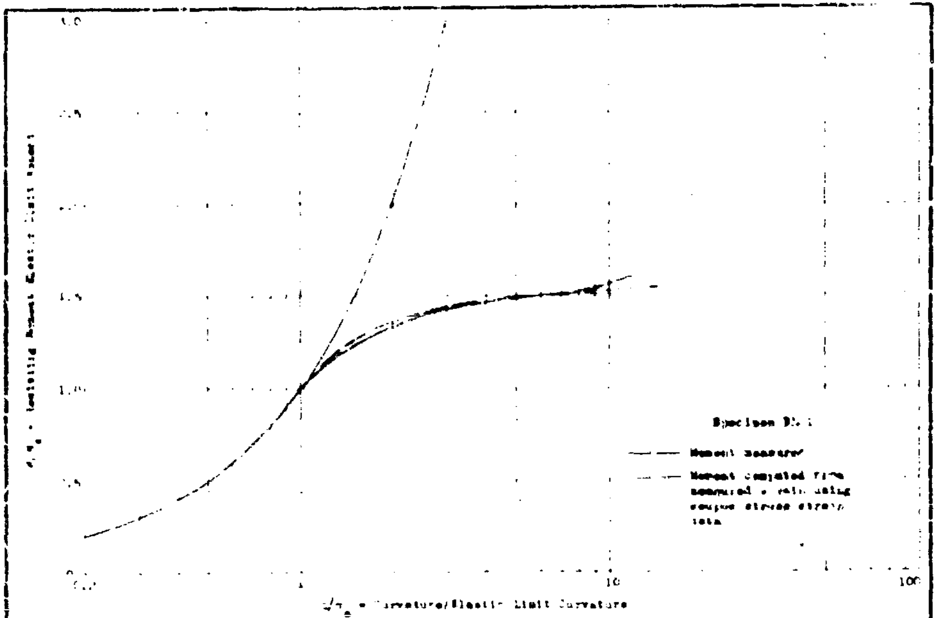
RESISTING MOMENT - CURVATURE



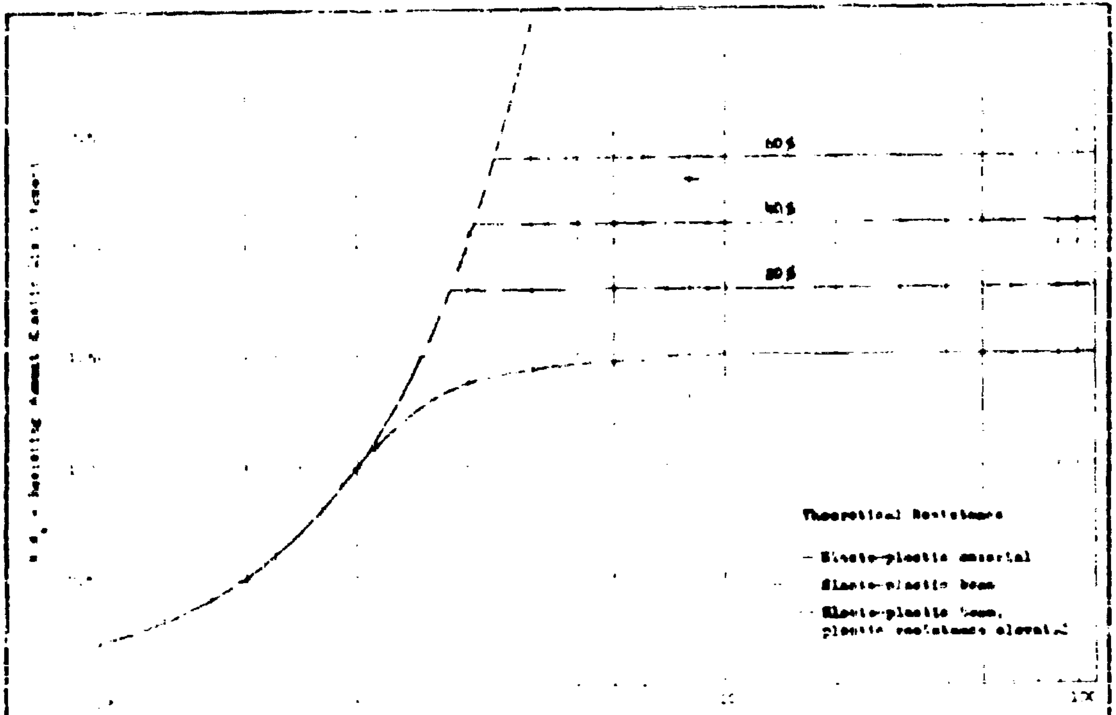
RESISTING MOMENT - CURVATURE



RL Series
Measured moment
10



RESISTING MOMENT - CURVATURE



Curvature Elastic Limit Curvature

FIG. RESISTING MOMENT - CURVATURE

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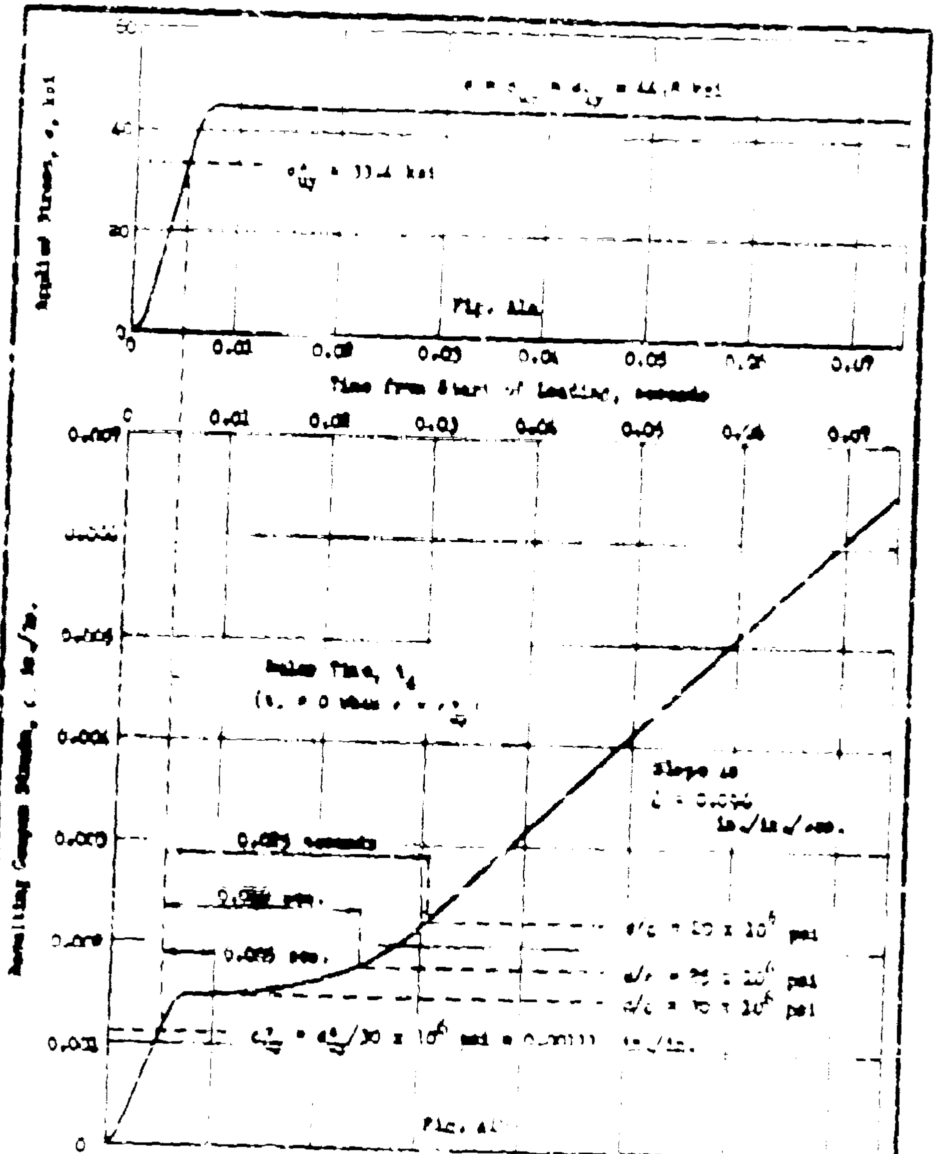

FIG. A1 TYPICAL RAPID COUPON TEST; APPLIED STRESS, RESULTING STRAIN

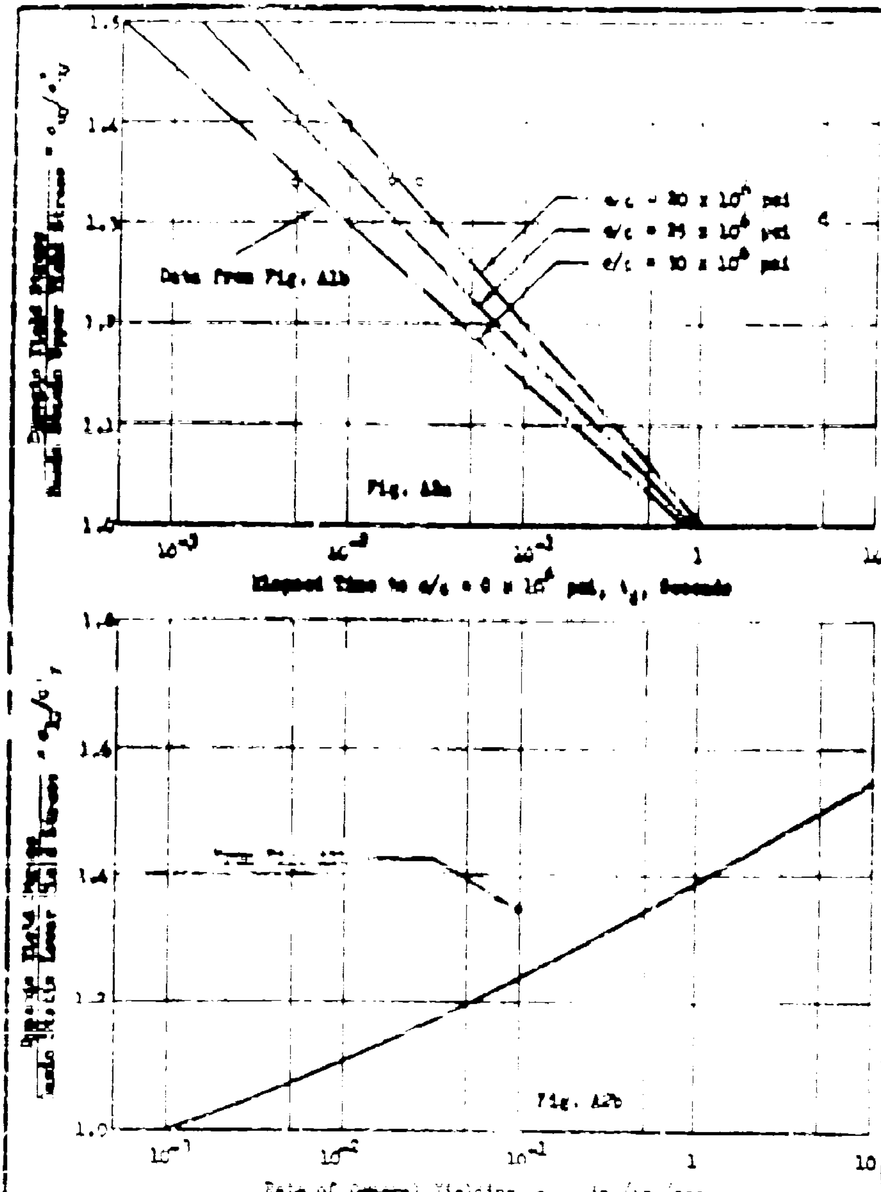

FIG. A2 DYNAMIC PROPERTIES OF BEAM MATERIAL

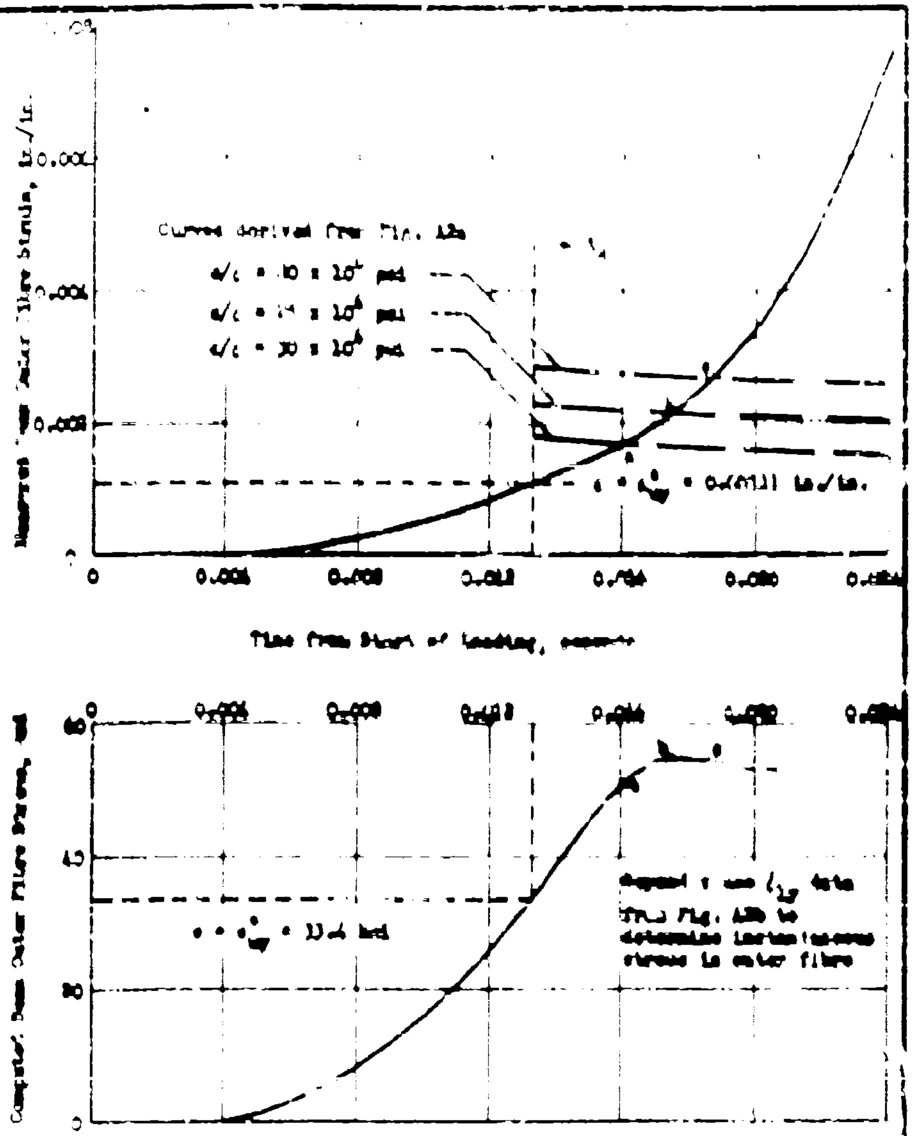

FIG. A3 DETERMINATION OF BEAM RESISTANCE FROM MEASURED STRAINS AND UNIAXIAL TIME DEPENDENT PROPERTIES OF MATERIALS

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